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High Altitude HVAC

Design Considerations

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HIGH ALTITUDE
HVAC DESIGN CONSIDERATIONS

- Goals
  - ❖Overview
  - ❖A Few Examples
  - ❖Thought Process
  - ❖Why
  - ❖(In the words of...) Understand, rather than......
- NOT
  - ❖Cookbook
  - ❖Substitute for engineering

Altitude Effects

- Baseball
  - ❖Home run distance
  - ❖Curve ball
- Basketball
  - ❖Doug Moe Era
- Football
  - ❖Field goal distance
- Similarities???
  - ❖Relation to air density
  - ❖Gravity???
  - ❖Function of oxygen content
  - ❖Heat Rejection
    - ➢Sensible?
    - ➢Latent?

Mitigating Factors

- Equipment counteracts using:
  - ❖ Temperature
  - ❖ Pressure
  - ❖ Humidity
  - ❖ Heat transfer
  - ❖ Equipment design basis

Altitude Dependent System/ Equipment Examples

- Airflow calculations
- Fans, ductwork (sizing, pressure)
- Air-cooled equipment
  - ➢ Condensers, chillers
  - ➢ Motors, electrical and electronic equipment
- Combustion equipment
  - ➢ Boilers, furnaces, generators, engines, gas absorption
- Pumps
- Evaporative coolers, Cooling towers
- Balancing, VAV box

Airflow Calculations – (Sensible Only)

- cfm = (Btu / hr) / (C_P * *p* * 60 * DT)
- Let C_P * *p* * 60 = F_{CFM} = "CFM transfer factor"
- cfm = (Btu / hr) / (F_{CFM} * DT)

Airflow Calculations – (Sensible Only)

OR

- cfm * F_{CFM} * DT = Btu / hr
- Look up F_{CFM} in tables (handout, 1st page)

THEN

- Check on Psych Chart

Reference page 1

ALTITUDE CORRECTIONS

ALTITUDE FEET	BAROMETER INCHES MERCURY	BAROMETER LBS/SQ IN ATMOS.	SPECIFIC VOLUME CU FT PER LB	REL DEN SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	29.92	14.7	13.340	1.000	.0750	1.080	1.000
100	29.81	14.64	13.389	.996	.0747	1.076	1.004
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9200	21.22	10.42	18.809	.709	.0532	.766	1.410
9400	21.06	10.34	18.961	.704	.0528	.760	1.421
9600	20.89	10.26	19.114	.698	.0524	.755	1.433
9800	20.73	10.18	19.265	.693	.0520	.749	1.444
10000	20.57	10.10	19.418	.687	.0515	.742	1.456

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ALTITUDE CORRECTIONS

ALTITUDE FEET	BAROMETER INCHES MERCURY	BAROMETER LBS/SQ IN ATMOS.	SPECIFIC VOLUME CU FT PER LB	REL DEN SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	29.92	14.7	13.340	1.000	.0750	1.080	1.000
100	29.81	14.64	13.389	.996	.0747	1.076	1.004
200	29.70	14.58	13.439	.993	.0745	1.073	1.007
300	29.60	14.52	13.488	.989	.0742	1.068	1.011
400	29.49	14.46	13.538	.985	.0739	1.064	1.015
500	29.38	14.40	13.587	.981	.0736	1.060	1.019
600	29.28	14.36	13.636	.978	.0734	1.057	1.022
700	29.17	14.32	13.686	.975	.0731	1.053	1.026
800	29.06	14.28	13.735	.971	.0728	1.048	1.030
900	28.96	14.24	13.785	.967	.0725	1.044	1.034
1000	28.85	14.20	13.834	.964	.0723	1.041	1.037
1100	28.75	14.14	13.883	.960	.0720	1.037	1.041
1200	28.65	14.08	13.933	.957	.0818	1.034	1.045
1300	28.54	14.02	13.982	.954	.0716	1.031	1.049
1400	28.44	13.96	14.031	.951	.0713	1.027	1.052
1500	28.33	13.90	14.081	.947	.0710	1.022	1.056
1600	28.23	13.86	14.130	.944	.0708	1.020	1.060
1700	28.13	13.82	14.179	.940	.0705	1.015	1.064
1800	28.02	13.78	14.228	.936	.0702	1.011	1.068
1900	27.92	13.74	14.278	.933	.0700	1.008	1.071

…TIONS

ALTITUDE FEET	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	.0750	1.080	1.000
100	.0747	1.076	1.004
200	.0745	1.073	1.007
300	.0742	1.068	1.011
400	.0739	1.064	1.015
500	.0736	1.060	1.019
4400	.0644	.927	1.166
4600	.0638	.919	1.175
4800	.0634	.913	1.184
5000	.0629	.906	1.193
	.0624	.899	1.202
5200	.0619	.891	1.212
5400	.0614	.884	1.222

Airflow Calculations (page 2)

- Example - sea level
  - 10,000 Btuh, 20F DT
  - cfm = (Btu / hr) / (F_{CFM} * DT)
  - cfm = 10,000 Btuh / (1.08 * 20) = 463

Airflow Calculations (page 3)

- Example - 5,200 ft. elevation
  - 10,000 Btuh, 20F DT
  - cfm = (Btu / hr) / (F_{CFM} * DT)
  - cfm = 10,000 Btuh / (0.891 * 20) = 561
  - Note, for simplicity, many applications are close enough using 0.9 in lieu of o.891

Standard and Actual Air

- Standard air, SCFM, is at sea level and 70°F
- Actual air, ACFM, is at actual conditions
- To convert, correct for density change due to both altitude and temperature
- For altitude: SCFM = ACFM * (density ratio)
- Example, 1000 CFM at 5,200 ft. elevation (equiv. mass):
  - 825 SCFM = 1,000 ACFM * 0.825

Fan and Duct System Pressure Drop Calculations (Example)

- Separate items using sea level data from items using altitude data (e.g. duct friction)
- Example (5,200 ft. elevation, 10,000 CFM)

Example (5,200 ft. elevation, 10,000 CFM)

	Sea level DP " w.c.	Alt. DP " w.c.
Cooling coil (computer sel.)		0.6
Heating coil (computer sel.)		0.2
Ductwork (ductilator)	1.5	
Fittings (ASHRAE tables)	2.0	
Other (diffuser, louvers, dampers)	1.5	
Total	5.0	0.8

Example (5,200 ft. elevation, 10,000 CFM) (page 2)

- (example continued)
  - Correct sea level items: 5.0 * 0.825 = 4.125
  - Total = 4.125 + 0.8 = 4.925 at alt.
  - At sea level = 4.925/.825 = 6”
- Fan selection
- Use computer selection at altitude, OR

Example (5,200 ft. elevation, 10,000 CFM) (page 3)

- Select from sea level tables or graphs:
  - RPM is the same at higher altitude (e.g. 1200 RPM)
  - CFM is the same at higher altitude (e.g. 10,000 CFM)
  - Correct brake horsepower by density ratio, for example 10 HP from sea level chart becomes 10 * 0.825 = 8.25 at 5,200 ft. altitude
- (More on pg. 7 of handout)

Reference page 7

obtain the BHP at 600°F. If the rating table showed 30.0 BHP, the actual would be 30.0 (530/1060) = 15.0 BHP.

It often happens that a fan, at startup, will handle cold air, and after running for a period will handle hot air. Such might be the case in an oven exhaust system. If **Example 2** were such a case, the fan would require 30.0 BHP when operating at 70°F., and 15.0 BHP when the oven had warmed to 600°F. Very often a damper is furnished with the fan so that, during the warming-up period, the fan can be dampered to reduce the horsepower. Without the damper, a 30 HP motor would be needed. If the warm-up period lasts only a couple of minutes, a motor half-way between hot and cold horsepower requirements could be selected.

Confusion may be avoided by specifying at what temperature the static pressure was calculated. In **Example 2**, the specifications should read either:

"11,000 CFM and 6"SP at 600°F." or
"11,000 CFM for operation at 600°F and 12"SP at 70°F."

Table 1 gives correction factors to use to convert from the density of non-standard temperature air to the density of 70°F. air. These factors are merely the ratios of absolute temperatures. Dividing static pressure and brake horsepower at 70°F. by the factor for a particular temperature will give the static pressure and brake horsepower at that temperature.

Temperature Correction factors

Table 1
CORRECTIONS FOR TEMPERATURE

Air Temp., Deg. F.	Factor	Air Temp., Deg. F.	Factor
—50	0.77	275	1.39
—25	0.82	300	1.43
0	0.87	325	1.48
+20	0.91	350	1.53
40	0.94	375	1.58
60	0.98	400	1.62
70	1.00	450	1.72
80	1.02	500	1.81
100	1.06	550	1.91
120	1.09	600	2.00
140	1.13	650	2.10
160	1.17	700	2.19
180	1.21	750	2.28
200	1.25	800	2.38
225	1.29	900	2.56
250	1.34	1000	2.76

At the end of this article, the factors that determine the best location for the fan in a hot process system are discussed.

2.

How to Calculate Actual Fan Performance at Other Than Sea Level

When a fan operates at some altitude above sea level, it handles air less dense than standard. This is similar to the case of the fan handling high temperature air, since in both cases the air is less dense than standard. **Table 2** gives the ratio of standard air density at sea level to densities at 70°F. at other altitudes.

Altitude Correction factors

Table 2
CORRECTIONS FOR ALTITUDE

Altitude, Ft. Above Sea Level	Factor	Altitude, Ft. Above Sea Level	Factor
0	1.00	5000	1.20
500	1.02	5500	1.22
1000	1.04	6000	1.25
1500	1.06	6500	1.27
2000	1.08	7000	1.30
2500	1.10	7500	1.32
3000	1.12	8000	1.35
3500	1.14	8500	1.37
4000	1.16	9000	1.40
4500	1.18	10000	1.45

Example 3. Required: 5800 CFM at 6"SP at 5000 ft. altitude. Air at sea level weighs 1.20 times as much as air at 5000 ft.; therefore, sea level SP = 1.20 x 6 = 7.20"SP. Select a fan for 5800 CFM at 7.20"SP and divide the rating table brake horsepower at 1.20.

Where both heat and altitude are combined, the air is rarified by each, independently, so that the factors that are to be used can be multiplied together.

Example 4. Required: 5800 CFM at 6"SP at 600°F. at 5000 ft. altitude. Air at 70°F. at sea level weighs 2.00 x 1.20 = 2.40 times as much as air at 600°F., 5000 ft. altitude. At sea level and 70°F., SP = 2.40 x 6 = 14.4"SP. Select a fan for 5800 CFM at 14.4"SP. Divide the brake horsepower in the rating table by 2.40 to obtain horsepower at 600°F. and 5000 ft. If the fan is to start cold, it will still be at 5000 ft. altitude. Therefore, to get the "cold" horsepower requirement, divide by 1.20, the altitude factor, only.

Density Changes From Other Than Heat and Altitude

Fan densities may vary from standard for other reasons than heat and altitude. Moisture, gas (other than air) or mixtures of gases are only a few possibilities. In these cases it is necessary to obtain the actual density of the inlet gas by some other reference material. A similar factor, as shown in **Table 1**, is then created as the standard density .075 lb. per cubic inch divided by the new density.

$$\text{Factor} = \frac{.075}{\text{special gas density}}$$

(7)

Density correction

Table 1
CORRECTIONS FOR TEMPERATURE

Air Temp., Deg. F.	Factor	Air Temp., Deg. F.	Factor
—50	0.77	275	1.39
—25	0.82	300	1.43
0	0.87	325	1.48
+20	0.91	350	1.53
40	0.94	375	1.58
60	0.98	400	1.62
70	1.00	450	1.72
80	1.02	500	1.81
100	1.06	550	1.91
120	1.09	600	2.00
140	1.13	650	2.10
160	1.17	700	2.19
180	1.21	750	2.28
200	1.25	800	2.38
225	1.29	900	2.56
250	1.34	1000	2.76

Table 2
CORRECTIONS FOR ALTITUDE

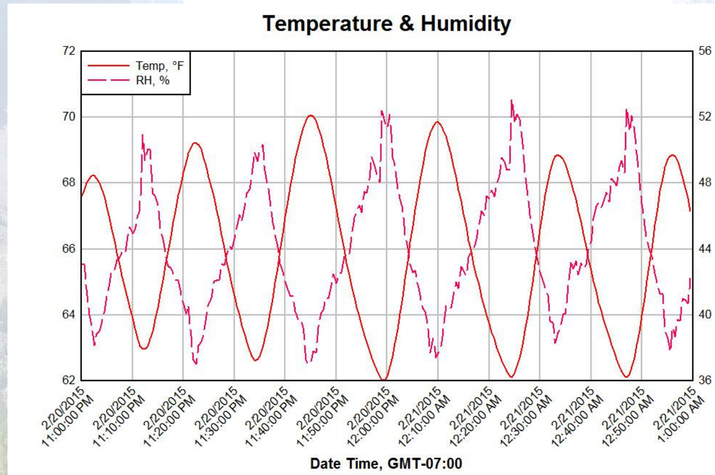
Altitude, Ft. Above Sea Level	Factor	Altitude, Ft. Above Sea Level	Factor
0	1.00	5000	1.20
500	1.02	5500	1.22
1000	1.04	6000	1.25
1500	1.06	6500	1.27
2000	1.08	7000	1.30
2500	1.10	7500	1.32
3000	1.12	8000	1.35
3500	1.14	8500	1.37
4000	1.16	9000	1.40
4500	1.18	10000	1.45

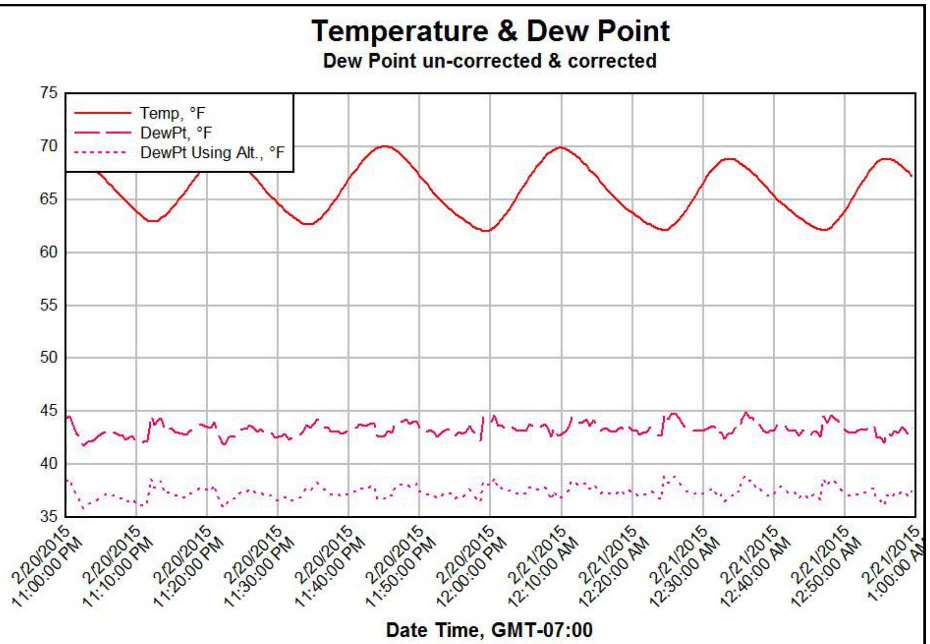
Density correction

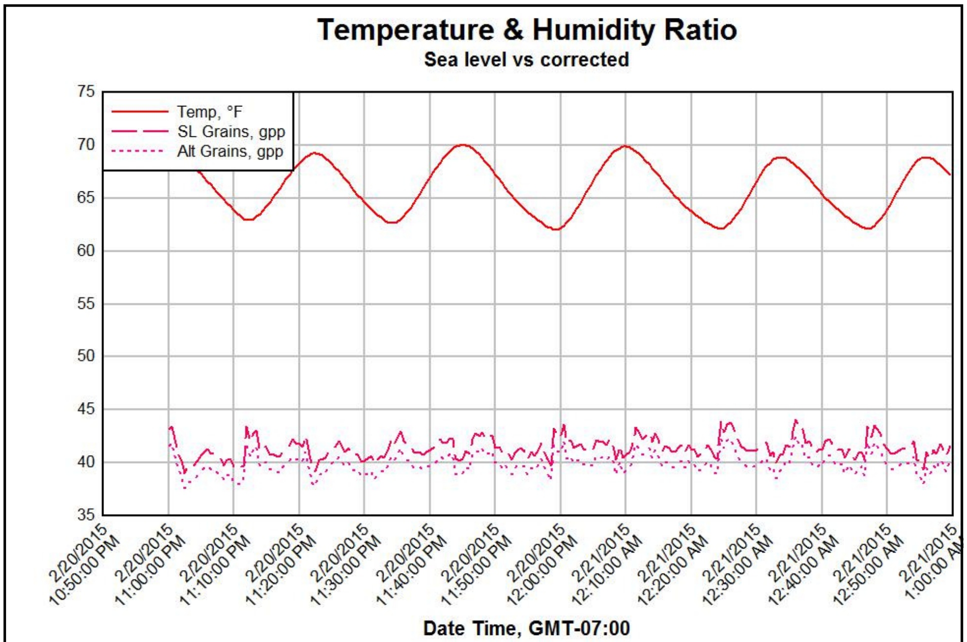
Fan and Duct System Calculations (page 3)

- The selection is thus 10,000 CFM, 1200 RPM, 4.9” s.p., AT 5200 FT. ALTITUDE – or
- 10,000 CFM, 1200 RPM, 6.0” s.p., AT SEA LEVEL
- Remember, derate the motor due to less motor cooling at higher altitude and add appropriate safety factors

Measurements or Data Logging
What needs correction?

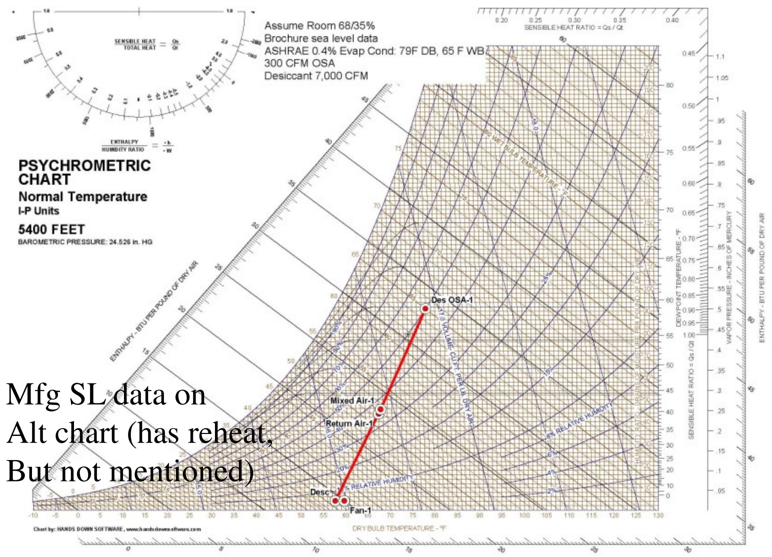


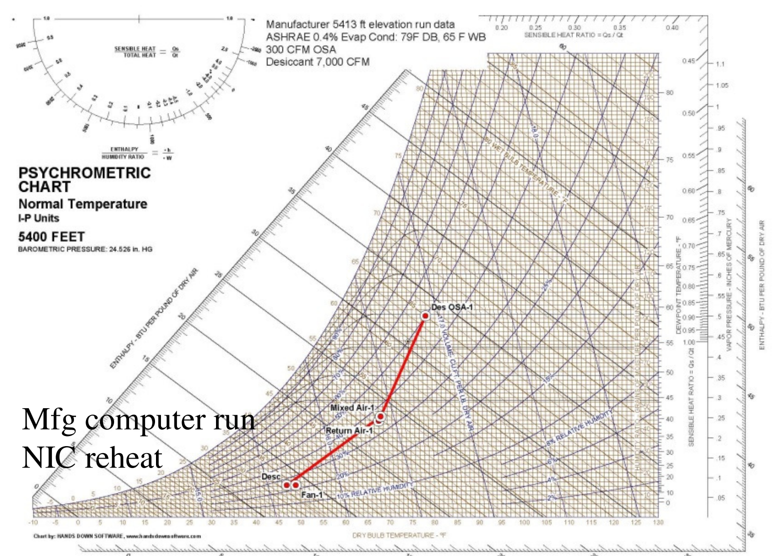




Desiccant Dehumidification

- Function of mass transfer & heat transfer, plus …
- Air is less dense at altitude
  - ❖ Less dehumidification capacity
- Use manufacturer's data if avail & if trust
- Otherwise, approx.: try derate of latent capacity by density ratio
  - ❖ Plot on psych chart using same CFM to determine dew point, etc.


Assume Room 68/35%
Brochure sea level data
ASHRAE 0.4% Evap Cond: 79F DB, 65 F WB
300 CFM OSA
Desiccant 7,000 CFM
PSYCHROMETRIC CHART
Normal Temperature
I-P Units
5400 FEET
BAROMETRIC PRESSURE: 24.526 in. HG
Des OSA-1
Mixed Air-1
Return Air-1
Desc
Fan-1
Mfg SL data on
Alt chart (has reheat,
But not mentioned)


Manufacturer 5413 ft elevation run data
ASHRAE 0.4% Evap Cond: 79F DB, 65 F WB
300 CFM OSA
Desiccant 7,000 CFM
PSYCHROMETRIC CHART
Normal Temperature
I-P Units
5400 FEET
BAROMETRIC PRESSURE: 24.526 in. HG
Des OSA-1
Mixed Air-1
Return Air-1
Desc
Fan-1
Mfg computer run
NIC reheat

Desiccant Dehumidification

- Verify if data includes reheat
- Example
- Sea Level data plotted on Alt chart
  - ❖164 MBH latent
  - ❖231 MBH total
- 5400 ft Air density ratio: 0.819
- Mfg run at alt plotted on psych chart
  - ❖124 MBH latent
  - ❖256 MBH total
- Note: SL data from Lit includes internal reheat. Mfg run above does not.
- Ratio, Latent: 0.756

Condensers, Air-cooled Chillers

- Packaged equipment:
  - ➢Lower air density = less heat rejection = higher temperatures = more heat rejection
  - ➢Therefore, counteracting forces. Net capacity reduction is typically less than air density ratio

Packaged equipment (page 2)

- Function of specific equipment design, refrigerant pressures, operating conditions, etc. Use manufacturer published corrections for altitude or call the manufacturer.
- Note in one Mfg's literature that correction factors for 5000 ft. elevation for air cooled condensers is 0.90 and for air cooled chillers is 0.97 for SPECIFIC series of equipment.

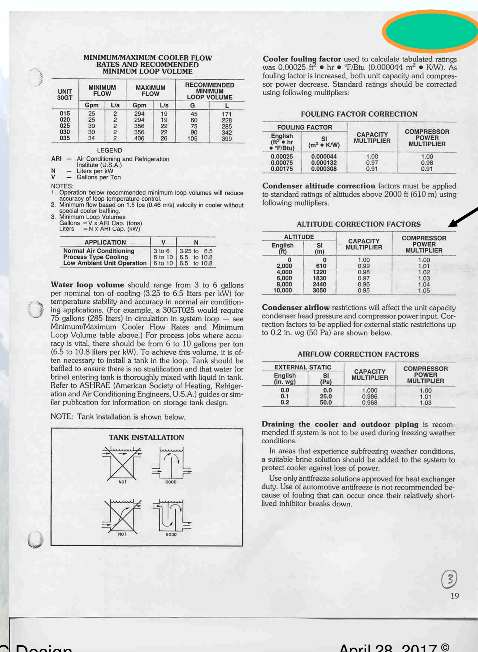
Air-cooled Chillers (page 1)

- Note Mfg A, Model B chiller data lists an 0.97 capacity correction factor for 6000 ft. altitude.
- Get the data for your specific application and selection if you need the accuracy.

Air-cooled Chillers (page 2)

- Mfg C, Model D literature lists capacity correction factors which combine fouling factor, chilled water DT, and altitude,
- and varies from 0.871 to 0.96 for 6000 ft. altitude. The correction from the standard condition (sea level, 10F DT, 0.00025 fouling factor, is 0.94.

Reference Page 3



MINIMUM/MAXIMUM COOLER FLOW RATES AND RECOMMENDED MINIMUM LOOP VOLUME

UNIT 30GT	MINIMUM FLOW		MAXIMUM FLOW		RECOMMENDED MINIMUM LOOP VOLUME	
	Gpm	L/a	Gpm	L/s	G	L
015	25	2	294	19	45	171
020	25	2	294	19	60	228
025	30	2	356	22	75	285
030	30	2	356	22	90	342
035	34	2	406	26	105	399

LEGEND

ARI — Air Conditioning and Refrigeration Institute (U.S.A.)
N — Liters per kW
V — Gallons per Ton

NOTES:
1. Operation below recommended minimum loop volumes will reduce accuracy of loop temperature control.
2. Minimum flow based on 1.5 fps (0.46 m/s) velocity in cooler without special cooler baffling.
3. Minimum Loop Volumes
   Gallons = V x ARI Cap. (tons)
   Liters = N x ARI Cap. (kW)

APPLICATION	V	N
Normal Air Conditioning	3 to 6	3.25 to 6.5
Process Type Cooling	6 to 10	6.5 to 10.8
Low Ambient Unit Operation	6 to 10	6.5 to 10.8

Water loop volume should range from 3 to 6 gallons per nominal ton of cooling (3.25 to 6.5 liters per kW) for temperature stability and accuracy in normal air conditioning applications. (For example, a 30GT025 would require 75 gallons (285 liters) in circulation in system loop — see Minimum/Maximum Cooler Flow Rates and Minimum Loop Volume table above.) For process jobs where accuracy is vital, there should be from 6 to 10 gallons per ton (6.5 to 10.8 liters per kW). To achieve this volume, it is often necessary to install a tank in the loop. Tank should be baffled to ensure there is no stratification and that water (or brine) entering tank is thoroughly mixed with liquid in tank. Refer to ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers, U.S.A.) guides or similar publication for information on storage tank design.

NOTE: Tank installation is shown below.

TANK INSTALLATION

Cooler fouling factor used to calculate tabulated ratings was 0.00025 $ft^2 \bullet hr \bullet °F/Btu$ (0.000044 $m^2 \bullet K/W$). As fouling factor is increased, both unit capacity and compressor power decrease. Standard ratings should be corrected using following multipliers:

FOULING FACTOR CORRECTION

FOULING FACTOR		CAPACITY MULTIPLIER	COMPRESSOR POWER MULTIPLIER
English ($ft^2 \bullet hr \bullet °F/Btu$)	SI ($m^2 \bullet K/W$)		
0.00025	0.000044	1.00	1.00
0.00075	0.000132	0.97	0.98
0.00175	0.000308	0.91	0.91

Condenser altitude correction factors must be applied to standard ratings of altitudes above 2000 ft (610 m) using following multipliers.

ALTITUDE CORRECTION FACTORS

ALTITUDE		CAPACITY MULTIPLIER	COMPRESSOR POWER MULTIPLIER
English (ft)	SI (m)		
0	0	1.00	1.00
2,000	610	0.99	1.01
4,000	1220	0.98	1.02
6,000	1830	0.97	1.03
8,000	2440	0.96	1.04
10,000	3050	0.95	1.05

Condenser airflow restrictions will affect the unit capacity condenser head pressure and compressor power input. Correction factors to be applied for external static restrictions up to 0.2 in. wg (50 Pa) are shown below.

AIRFLOW CORRECTION FACTORS

EXTERNAL STATIC		CAPACITY MULTIPLIER	COMPRESSOR POWER MULTIPLIER
English (in. wg)	SI (Pa)		
0.0	0.0	1.000	1.00
0.1	25.0	0.986	1.01
0.2	50.0	0.968	1.03

Draining the cooler and outdoor piping is recommended if system is not to be used during freezing weather conditions.

In areas that experience subfreezing weather conditions, a suitable brine solution should be added to the system to protect cooler against loss of power.

Use only antifreeze solutions approved for heat exchanger duty. Use of automotive antifreeze is not recommended because of fouling that can occur once their relatively short-lived inhibitor breaks down.

3

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Altitude Correction factors

ALTITUDE CORRECTION FACTORS

ALTITUDE English (ft)	ALTITUDE SI (m)	CAPACITY MULTIPLIER	COMPRESSOR POWER MULTIPLIER
0	0	1.00	1.00
2,000	610	0.99	1.01
4,000	1220	0.98	1.02
6,000	1830	0.97	1.03
8,000	2440	0.96	1.04
10,000	3050	0.95	1.05

Reference
Page 5

Performance Adjustment Factors (Cont.)

GLYCOL AND PERFORMANCE ADJUSTMENT FACTORS

Table 18-1 — Performance Adjustment Factors (20-60 Ton Units Only)

Fouling Factor	Chilled Water ΔT	Sea Level CAP	Sea Level GPM	Sea Level KW	2,000 Feet CAP	2,000 Feet GPM	2,000 Feet KW	4,000 Feet CAP	4,000 Feet GPM	4,000 Feet KW	6,000 Feet CAP	6,000 Feet GPM	6,000 Feet KW
0.00025	6	0.987	1.650	0.993	0.967	1.640	1.003	0.952	1.620	1.019	0.932	1.570	1.029
	8	0.993	1.250	0.997	0.973	1.240	1.007	0.956	1.220	1.025	0.935	1.190	1.035
	10	1.000	1.000	1.000	0.980	0.990	1.010	0.960	0.970	1.030	0.940	0.940	1.040
	12	1.007	0.820	1.003	0.987	0.810	1.013	0.966	0.800	1.035	0.945	0.780	1.045
	14	1.013	0.710	1.007	0.993	0.700	1.017	0.972	0.680	1.038	0.952	0.660	1.048
	16	1.020	0.640	1.010	1.000	0.630	1.020	0.980	0.620	1.040	0.960	0.600	1.050
0.001	6	0.957	1.615	0.979	0.953	1.600	0.989	0.931	1.570	0.990	0.914	1.540	1.002
	8	0.964	1.215	0.982	0.959	1.210	0.992	0.937	1.180	0.994	0.920	1.170	1.006
	10	0.970	0.965	0.985	0.964	0.960	0.995	0.943	0.940	0.998	0.926	0.920	1.009
	12	0.976	0.785	0.989	0.966	0.790	0.998	0.945	0.770	1.007	0.926	0.760	1.018
	14	0.982	0.675	0.993	0.968	0.670	1.001	0.947	0.650	1.016	0.927	0.640	1.027
	16	0.989	0.620	0.996	0.970	0.600	1.004	0.949	0.590	1.025	0.927	0.580	1.036
0.002	6	0.916	1.565	0.951	0.913	1.550	0.969	0.896	1.490	0.975	0.871	1.450	0.984
	8	0.923	1.245	0.958	0.919	1.170	0.972	0.898	1.110	0.979	0.874	1.080	0.987
	10	0.930	0.925	0.965	0.925	0.920	0.975	0.900	0.890	0.982	0.877	0.880	0.989
	12	0.934	0.810	0.969	0.927	0.750	0.978	0.908	0.730	0.986	0.885	0.720	0.993
	14	0.938	0.695	0.973	0.929	0.640	0.981	0.916	0.620	0.989	0.894	0.610	0.997
	16	0.948	0.580	0.976	0.931	0.580	0.983	0.924	0.580	0.993	0.902	0.570	1.001

Table 18-2 — Performance Adjustment Factors (10 & 15 Ton Units Only)

Fouling Factor	Chilled Water ΔT	Sea Level CAP	Sea Level GPM	Sea Level KW	2,000 Feet CAP	2,000 Feet GPM	2,000 Feet KW	4,000 Feet CAP	4,000 Feet GPM	4,000 Feet KW	6,000 Feet CAP	6,000 Feet GPM	6,000 Feet KW
0.00025	6	1.00	1.66	1.00	0.98	1.63	1.01	0.95	1.59	1.02	0.93	1.54	1.05
	8	1.00	1.25	1.00	0.98	1.22	1.01	0.96	1.19	1.02	0.93	1.16	1.05
	10	1.00	1.00	1.00	0.98	0.98	1.01	0.95	0.95	1.02	0.92	0.92	1.04
	12	1.00	0.83	1.00	0.98	0.81	1.01	0.95	0.79	1.02	0.92	0.77	1.04
	14	0.99	0.71	1.00	0.97	0.59	1.01	0.95	0.68	1.02	0.92	0.66	1.04
0.001	6	0.96	1.60	0.98	0.94	1.57	0.99	0.92	1.53	1.00	0.90	1.49	1.01
	8	0.96	1.20	0.98	0.94	1.18	0.99	0.92	1.15	1.00	0.90	1.12	1.01
	10	0.96	0.96	0.98	0.94	0.94	0.99	0.92	0.92	1.00	0.89	0.89	1.01
	12	0.96	0.80	0.98	0.94	0.79	0.99	0.92	0.77	1.00	0.89	0.74	1.01
	14	0.96	0.68	0.98	0.94	0.67	0.99	0.92	0.65	1.00	0.89	0.66	1.01
0.002	8	0.93	1.15	0.95	0.91	1.13	0.96	0.88	1.10	0.98	0.86	1.07	0.99
	10	0.90	0.90	0.94	0.89	0.88	0.95	0.87	0.87	0.96	0.85	0.84	0.98
	12	0.90	0.75	0.94	0.88	0.73	0.95	0.86	0.72	0.95	0.84	0.70	0.98
	14	0.90	0.64	0.94	0.87	0.63	0.95	0.86	0.82	0.95	0.84	0.60	0.98

*Standard chilled water Δ is 8-12 for CGA 120-180.
Standard chilled water Δ is 6-16 for CGAE 20-60.

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Performance Adjustment Factors (20-60 Ton Units Only)

Fouling Factor	Chilled Water ΔT	Altitude								
		Sea Level			2,000 Feet			4,000 Feet		
		CAP	GPM	KW	CAP	GPM	KW	CAP	GPM	KW
0.00025	6	0.987	1.650	0.993	0.967	1.640	1.003	0.952	1.620	1.019
	8	0.993	1.250	0.997	0.973	1.240	1.007	0.956	1.220	1.025
	10	1.000	1.000	1.000	0.980	0.990	1.010	0.960	0.970	1.030
	12	1.007	0.820	1.003	0.987	0.810	1.013	0.966	0.800	1.035
	14	1.013	0.710	1.007	0.993	0.700	1.017	0.972	0.680	1.038
	16	1.020	0.640	1.010	1.000	0.630	1.020	0.980	0.620	1.040
0.001	6	0.957	1.615	0.979	0.953	1.600	0.989	0.931	1.570	0.990
	8	0.964	1.215	0.982	0.959	1.210	0.992	0.937	1.180	0.994
	10	0.970	0.965	0.985	0.964	0.960	0.995	0.943	0.940	0.998
	12	0.976	0.785	0.989	0.966	0.790	0.998	0.945	0.770	1.007
	14	0.982	0.675	0.993	0.968	0.670	1.001	0.947	0.650	1.016
	16	0.989	0.620	0.996	0.970	0.600	1.004	0.949	0.590	1.025
0.002	6	0.916	1.565	0.951	0.913	1.550	0.969	0.896	1.490	0.975
	8	0.923	1.245	0.958	0.919	1.170	0.972	0.898	1.110	0.979
	10	0.930	0.925	0.965	0.925	0.920	0.975	0.900	0.890	0.982
	12	0.934	0.810	0.969	0.927	0.750	0.978	0.908	0.730	0.986
	14	0.938	0.695	0.973	0.929	0.640	0.981	0.916	0.620	0.989
	16	0.948	0.580	0.976	0.931	0.580	0.983	0.924	0.580	0.993

Air-cooled Electric Motors

- Limited by allowable temperature
- Higher altitude = less air = less cooling = lower rated capacity
- Standard motors rated at 1,000 meters (3,300 ft.) altitude
- Again, manufacturer's design details are a factor. When critical, get data from the selected manufacturer.

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APPLICATION DATA—AC AND DC

difference between the highest and lowest peak amplitudes of the current pulses over one cycle exceed 10 percent of the highest pulse amplitude at rated armature current.

e. Low noise levels are required.

3. Operation at speeds above the highest rated speed.
4. Operation in a poorly ventilated room, in a pit, or in an inclined position.
5. Operation where subjected to:
   a. Torsional impact loads.
   b. Repetitive abnormal overloads.
   c. Reversing or electric braking.
6. Operation of machine at standstill with any winding continuously energized or of short-time rated machine with any winding continuously energized.
7. Operation of direct-current machine where the average armature current is less than 50 percent of the rated full-load amperes over a 24-hour period, or continuous operation at armature current less than 50 percent of rated current for more than 4 hours.

Authorized Engineering Information 10-27-1926, revised 11-11-1965; 11-16-1967; 7-15-1970; 1-25-1972; 11-8-1973; 3-14-1979.

MG 1-14.04 Operation at Altitudes Above 3300 Feet (1000 Meters)

The temperature rises given for motors and generators in MG 1-12.41, MG 1-12.42, MG 1-12.62 and MG 1-15.41 are based upon operation at altitudes of 3300 feet (1000 meters) or less and a maximum ambient temperature of 40°C. It is also recognized as good practice to use motors and generators at altitudes greater than 3300 feet (1000 meters) as indicated in the following paragraphs:

A. Motors and generators having Class A or B insulation systems and temperature rises in accordance with MG 1-12.41, MG 1-12.42, MG 1-12.62 and MG 1-15.41 will operate satisfactorily at altitudes above 3300 feet (1000 meters) in those locations where the decrease in ambient temperature compensates for the increase in temperature rise, as follows:

Motor Rating limits

Ambient Temperature, Degrees C	Maximum Altitude, Feet (Meters)
40	3300 (1000)
30	6600 (2000)
20	9900 (3000)

B. Motors having a service factor of 1.15 or higher will operate satisfactorily at unity service factor at an ambient temperature of 40°C at altitudes above 3300 feet (1000 meters) up to 9000 feet (2740 meters).

C. Motors and generators which are intended for use at altitudes above 3300 feet (1000 meters) at an ambient temperature of 40°C should have temperature rises at sea level not exceeding the values calculated from the following formula:

When altitude in feet:

$$T_{RSL} = T_{RA}\left[1 - \frac{(Alt - 3300)}{33000}\right]$$

—or—

When altitude in meters:

$$T_{RSL} = T_{RA}\left[1 - \frac{(Alt - 1000)}{10000}\right]$$

where:

T_{RSL} = test temperature rise in degrees C at sea level.
T_{RA} = temperature rise in degrees C from the appropriate table in MG 1-12.41, MG 1-12.42, MG 1-12.62 or MG 1-15.41.
Alt = altitude above sea level in feet (meters) at which machine is to be operated.

D. Preferred values of altitude are 3300 feet (1000 meters), 6600 feet (2000 meters), 9900 feet (3000 meters), 13200 feet (4000 meters) and 16500 feet (5000 meters).

Authorized Engineering Information 11-12-1964.

MG 1-14.05 Short-time Rated Electrical Machines

Short-time rated electrical machines (see MG 1-10.35 and MG 1-10.63) should be applied so as to insure performance without injury. They should not be used (except on the recommendation of the manufacturer) on any application where the driven machine may be left running continuously.

NEMA Standard 10-29-1937.

MG 1-14.06 Direction of Rotation

Facing the end of the machine opposite the drive, the standard direction of rotation for all nonreversing direct-current motors, all alternating-current single-phase motors, all synchronous motors and all universal motors shall be counterclockwise. For alternating- and direct-current generators, the rotation shall be clockwise. Where two or more machines are mechanically coupled together, this standard may not apply to all units.

NEMA Standard 1-26-1934.

NOTE—This does not apply to polyphase induction motors as most applications on which they are used are of such a nature that either or both directions of rotation may be required, and the phase sequence of the power lines is rarely known.

Authorized Engineering Information 1-26-1934.

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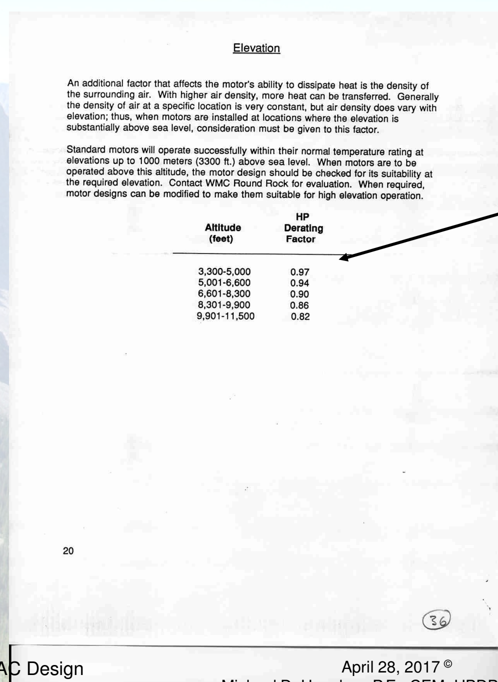
Motors with Class A or B insulation altitude rating increases as ambient temperature is lowered

Ambient Temperature, Degrees C	Maximum Altitude, Feet (Meters)
40	3300 (1000)
30	6600 (2000)
20	9900 (3000)

Air-cooled Electric Motors (page 2)

- ANSI / NEMA Standard MG-1
  - Motors rated at 40C which are intended for use above 1000 meters should have the allowable temperature rise reduced in accordance with mfg's formula
- Mfg E listed a correction factor for their Model F induction motor of 0.94 at altitudes from 5,001 ft. to 6,600 ft.

Reference Page 36



Elevation

An additional factor that affects the motor's ability to dissipate heat is the density of the surrounding air. With higher air density, more heat can be transferred. Generally the density of air at a specific location is very constant, but air density does vary with elevation; thus, when motors are installed at locations where the elevation is substantially above sea level, consideration must be given to this factor.

Standard motors will operate successfully within their normal temperature rating at elevations up to 1000 meters (3300 ft.) above sea level. When motors are to be operated above this altitude, the motor design should be checked for its suitability at the required elevation. Contact WMC Round Rock for evaluation. When required, motor designs can be modified to make them suitable for high elevation operation.

Altitude (feet)	HP Derating Factor
3,300-5,000	0.97
5,001-6,600	0.94
6,601-8,300	0.90
8,301-9,900	0.86
9,901-11,500	0.82

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Altitude Correction factors

Altitude (feet)	HP Derating Factor
3,300-5,000	0.97
5,001-6,600	0.94
6,601-8,300	0.90
8,301-9,900	0.86
9,901-11,500	0.82

Combustion Equipment

- Gravity, packaged equipment, AGA: de-rate by 4% / 1,000 ft. (volume of combustion air & flue gas increases about 4%/1,000 ft.)
  - Typically de-rate when above 2,000 ft. elevation
  - Often reduce gas orifice size to match gas input to altitude air
  - Some boiler manufacturers have condensing boilers with "lower altitude derates".

Combustion Equipment (page 2)

- Design Options
  - Decrease gas manifold pressure
  - Increase gas orifice pressure loss (smaller orifices)
  - Increase airflow (mass flow) with power burner fan, forced draft fan, or induced draft fan

Combustion Equipment (page 3)

- Gas Heat Content
  - Reduces according to the air density ratio
  - Typically 1,000 BTU per Cu. Ft. at sea level, 830 BTU per Cu. Ft. at 5,000 ft. altitude, etc.

- Some utilities vary the heat content, therefore call the utility for the specific location. Some increase the heat content to achieve 1,000 BTU per Cu. Ft. at 5,000 ft. altitude.

(see "Boiler House Journal", near end of handout)

Hugo, CO vs. Denver

- Altitude 5046
- Btu content: 780
- SG: 0.65
- Peoples Gas Company

- 5280
- 831
- 0.67
- Excel Energy

Las Animas, CO vs. Denver

- Altitude: 3901
- Btu content: 735
- SG: 0.62
- Citizen's Utility Company
  - ❖ Internet search – not found
  - ❖ Black Hills Energy?

- 5280
- 831
- 0.67
- Excel Energy

Combustion Equipment (page 4)

- Flue Design
  - Available draft decreases substantially at higher altitudes
  - Follow the manufacturer's procedures or ASHRAE procedures, which account for altitude barometric pressure

Pumps

- Three concerns:
  - NPSH
  - Cavitation
  - Motor cooling / rating
- All are air density related
  - Use the standard formulas with actual barometric pressure data
- NPSH: less barometric pressure on open systems, 6 ft. less at 5000 ft. altitude
- Cavitation: less barometric pressure on open systems

Reference
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NET POSITIVE SUCTION HEAD

(NPSH)

NPSH combines all of the factors limiting the suction side of a pump; internal pump losses, static suction lift, friction losses, vapor pressure and atmospheric conditions. It is important to differentiate between Required NPSH and Available NPSH.

Required NPSH - this refers to internal pump losses and is determined by laboratory test. It varies with each pump and with each pump capacity and speed change. The greater the capacity, the greater the required NPSH. Required NPSH must always be given by the pump manufacturer.

Available NPSH - this is a characteristic of the system. It can be calculated, or on an existing installation, it can be determined by field test using vacuum and pressure gauges. By definition, it is the net positive suction head above the vapor pressure available at the suction flange of the pump to maintain a liquid state. Since there are also internal pump losses (required NPSH) the available NPSH in a system must exceed the pump required NPSH -- otherwise, reduction in capacity, loss of efficiency, noise, vibration and cavitation will result.

NPSH FORMULAS

PROPOSED INSTALLATION
To calculate the N. P. S. H. available in a proposed application, the following formula is recommended:

$$Hsv = Hp \pm Hz - Hf - Hvp$$

Hsv = Available N. P. S. H. expressed in feet of fluid.

Hp = Absolute pressure on the surface of the liquid where the pump takes suction, expressed in "feet". This could be atmospheric pressure or vessel pressure (pressurized tank).

Hz = Static elevation of the liquid above, or below the centerline of the impeller, expressed in feet.

Hf = Friction and velocity head loss in the piping, also expressed in feet.

Hvp = Absolute vapor pressure of the fluid at the pumping temperature, expressed in feet of fluid.

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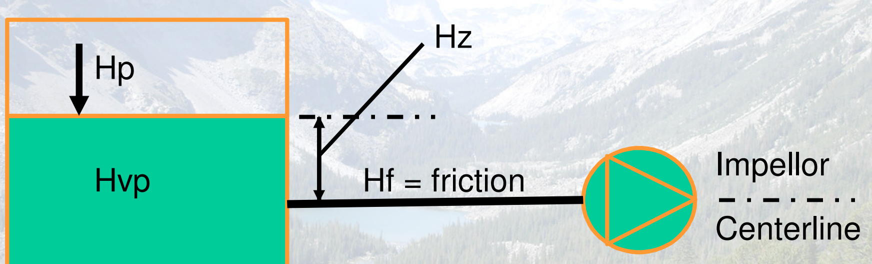
NPSH
Formula

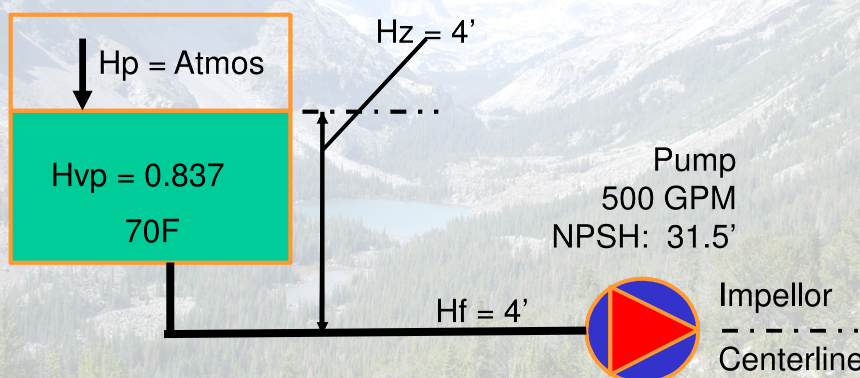
Available NPSH
Hsv = Hp ± Hz – Hf - Hvp



$$Hsv = Hp \pm Hz - Hf - Hvp$$

Hsv	=	Available N. P. S. H. expressed in feet of fluid.
Hp	=	Absolute pressure on the surface of the liquid where the pump takes suction, expressed in "feet". This could be atmospheric pressure or vessel pressure (pressurized tank).
Hz	=	Static elevation of the liquid above, or below the centerline of the impeller, expressed in feet.
Hf	=	Friction and velocity head loss in the piping, also expressed in feet.
Hvp	=	Absolute vapor pressure of the fluid at the pumping temperature, expressed in feet of fluid.

Example – Cooling Tower



Hsv = Hp ± Hz – Hf - Hvp

- Sea Level
  - ❖Hsv = 34’ + 4’ – 4’ – 1’ = 33’
  - ❖OK
- 5000 ft
  - ❖Hsv = 28’ + 4’ – 4’ – 1’ = 27’
  - ❖Will cavitate

Another NPSH Formula

- For your homework

Reference page 47

NPSH Formula

and to overcome the pump internal pressure losses is the *required NPSH* of the pump.

The required NPSH of a pump is part of the standard design performance data furnished by the manufacturer or of a design specific to a given process pump.

The net positive suction head (pressure in feet of liquid) of the process liquid system as it exists within the system complex at the entering (suction) side of the pump is called the *available NPSH*. It must be at least equal to or greater than the required NPSH in order to produce a flow thru a pump. A safety factor should be considered to cover a possible excess of required NPSH.

The available NPSH is the algebraic sum determined by the formula:

$$\text{Available NPSH} = \frac{2.31\ (P_a - P_{vp})}{\text{sp gr}} + H_s - H_f$$

where:

NPSH = net positive suction head (absolute pressure, ft)

2.31 = conversion factor to change one pound pressure at a specific gravity of 1.0 to pressure head in feet of water (1 inch Hg = 1.134 ft of water).

P_a = atmospheric pressure (absolute pressure, psia) in an open system; or pressure (absolute, psia) within a totally closed system.

P_{vp} = vapor pressure (psia) of the fluid at pumping temperature; in a totally closed system it is part of the total pressure P_a.

H_s = elevation head, static head (ft) above or below the pump center line. If above, positive static head; if below, negative static head, sometimes termed suction lift.*

H_f = friction head (ft) on the suction side of the system including piping, fittings, valves, heat exchangers at the design velocity (V_s in ft per sec) within suction system.

sp gr = specific gravity of liquid handled at operating temperature (Fig. 14).

Figures 11 and 12 illustrate the application of the calculation of available NPSH to the variety of open and closed circuits. Three additional terms are introduced in these figures:

H_{vp} = vapor pressure (ft) of the fluid at pumping temperature.

H_e = entrance head (ft), suction pipe entrance loss in open systems.

$H_{v_{se}}$ = pump suction eye velocity head (ft), $(V_{se})^2/2g$. This term is usually very small as shown in the following tabulation:

Velocity (ft/sec)	3	4	5	6	7
Velocity head (ft)	.14	.25	.39	.56	.76
Velocity (ft/sec)	8	9	10	11	12
Velocity head (ft)	.99	1.26	1.55	1.88	2.23

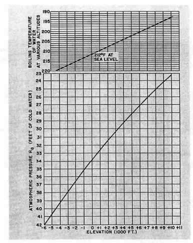


FIG. 13 — EFFECT OF ALTITUDE ON ATMOSPHERIC PRESSURE

A pressure selected to be maintained above atmospheric pressure in the top circuit of a closed piping system determines the design $H_{(expansion\ tanks)}$ pressure *(Fig. 12)*.

On examining *Fig. 11 and 12*, it is evident that the available NPSH may vary, especially with critical fluids. The variables that may be either fixed or adjusted are:

1. Altitude of the system location above or below sea level; *Fig. 13* shows the change of atmospheric pressure (feet of cold water) with the altitude. The greater the altitude, the lower is the available atmospheric pressure (P_a in psia or H_a in ft) which influences an open system. The totally closed system pressure P_a may be regulated.
2. Vapor pressure of the liquid *(Fig. 14)* pumped at operating temperature P_{vp} (psia) or H_{vp} (ft); *Figure 14* shows the vapor pressure of water at various temperatures. This pressure may or may not be adjusted.
3. Friction losses of the pump suction piping system; the larger the pipe, the less are the friction losses H_f (ft) for a given fluid flow.

*It must be remembered that a pump does not lift the liquid it moves; a pump must have pressure to produce the flow.

Carrier Air Conditioning Company

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$$\text{Available NPSH} = \frac{2.31\ (P_a - P_{vp})}{\text{sp gr}} + H_s - H_f$$

where:

NPSH = net positive suction head (absolute pressure, ft)

2.31 = conversion factor to change one pound pressure at a specific gravity of 1.0 to pressure head in feet of water (1 inch Hg = 1.134 ft of water).

P_a = atmospheric pressure (absolute pressure, psia) in an open system; or pressure (absolute, psia) within a totally closed system.

P_{vp} = vapor pressure (psia) of the fluid at pumping temperature; in a totally closed system it is part of the total pressure P_a.

H_s = elevation head, static head (ft) above or below the pump center line. If above, positive static head; if below, negative static head, sometimes termed suction lift.*

H_f = friction head (ft) on the suction side of the system including piping, fittings, valves, heat exchangers at the design velocity (V_s in ft per sec) within suction system.

sp gr = specific gravity of liquid handled at operating temperature (Fig. 14).

Figures 11 and 12 illustrate the application of the calculation of available NPSH to the variety of open and closed circuits. Three additional terms are introduced in these figures:

H_{vp} = vapor pressure (ft) of the fluid at pumping temperature.

H_e = entrance head (ft), suction pipe entrance loss in open systems.

$H_{v_{se}}$ = pump suction eye velocity head (ft), $(V_{se})^2/2g$. This term is usually very small as shown in the following tabulation:

Evaporative Coolers

- Significant Parameters
  - Mass Velocity
  - Air Density
  - Heat Transfer Coefficient, turbulence at boundary layer
  - Water Vapor Pressure
- Density and heat transfer coefficient and vapor pressure effects are compensating
  - Data hard to find, typically not derated for altitude
  - Accurate selections typically not needed

Reference
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High altitude effects on the performance of equipment involving water evaporation

ROBERT JORGENSEN
Member ASHRAE

There are many types of heating, refrigerating, and air-conditioning equipment which utilize the psychrometric process of evaporating water into air. These equipment types may be classified in two groups according to whether the main function is to: (1) increase the amount of water vapor in the air, or (2) remove heat from the water. Among the former are various types of humidifiers, air washers, and evaporative air coolers as listed in Chapter 38 of the Guide And Data Book.[1] Among the latter are various types of cooling towers and spray ponds as listed in Chapter 37 of the Guide And Data Book,[1] plus evaporative condensers as described in Chapter 32 of the Guide And Data Book[1] and air washers which may be considered a special form of cooling tower.

The purpose of this paper, like that of all the other papers presented at this Symposium, is to examine the methods of accounting for altitude effect which are in use. Hopefully, this will stimulate interest in improving on these methods and establishing standards. In order to keep this paper from becoming too long, only two types of equipment will be examined, one for each of the above categories. Perhaps as a result of this small start, studies covering all types will be made in the near future.

Robert Jorgensen is Chief Engineer, Air Handling Div, Buffalo Forge Co., Buffalo, N.Y.

AIR WASHERS FOR HUMIDIFYING DUTY

This Task Group was not able to find any published data giving the effect of altitude on the performance of air washers for humidifying duty. An analytical study was, therefore, made.

The Guide And Data Book[1] defines the humidifying effectiveness of a recirculated spray air washer as follows:

$$\eta = \frac{t_E - t_L}{t_E - t'}, \text{ where}$$

η = humidifying efficiency or effectiveness,
t_E = entering dry-bulb temperature,
t_L = leaving dry-bulb temperature, and
t' = entering (and leaving) wet-bulb temperature.

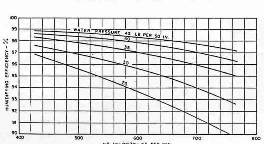

Fig. 1 Effect of air velocity and water pressure on humidifying efficiency

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"Humidification Effectiveness Formula

$$\eta = \frac{t_E - t_L}{t_E - t'}, \text{ where}$$

η = humidifying efficiency or effectiveness,
t_E = entering dry-bulb temperature,
t_L = leaving dry-bulb temperature, and
t' = entering (and leaving) wet-bulb temperature.

Cooling Towers

- Some controversy before computer selections
  - ❖Don’t derate but increase fan motor HP
  - ❖Don’t derate
  - ❖Don’t derate and reduce fan motor HP
  - ❖Add capacity at higher altitude

Cooling Towers

- For some (or most typical, higher WB) operating conditions, increased water partial pressure at higher altitudes may have a greater effect in increasing capacity than reduced density does in reducing capacity
- Cold air operation – economizers: less capacity.

Cooling Towers

- Data hard to find, normally included in selection software
- Some info at CTI.org/tech_papers

Reference
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The performance capabilities of an air washer are usually determined from tests on apparatus using recirculated spray water. It has been found that the value of humidifying efficiency or effectiveness for a given type of washer construction varies with air velocity and water pressure, as shown in Fig. 1.

It is this Task Group's belief that most of this type of information is obtained from sea level tests and is used without regard for the altitude of the application. Furthermore, this Task Group is unaware of any complaints about performance at altitude.

A quick comparison of air washers with other mass-transfer equipment suggests that mass velocity, rather than air velocity, is the significant parameter. If it is, then it would be proper to enter Fig. 1 with an equivalent air velocity based on an equal mass velocity. Since the equivalent velocity would be lower than the actual velocity, a higher efficiency would result and this might explain why no complaints have been noted.

The above conclusion can also be reached by noting the effect on efficiency of reducing the density in the following expression and assuming that all other factors are constant:

$$\eta = 1 - e^{-\frac{hS}{cV\delta}}$$ where

η = humidifying efficiency,
e = 2.718,
h = coefficient of heat transfer (air film)
S = interfacial area (between water and air),
c = specific heat (humid),
V = air velocity, and
δ = air density.

It should be observed that while the interfacial area (S) can be considered constant for a given air washer, and the specific heat (c) can be considered independent of altitude, the performance of an air washer at altitude will not equal that at the same air velocity (V) at sea level unless the effects of altitude on the density (δ) and the coefficient of heat transfer (h) are compensating. The effect of altitude on density can be determined from psychrometric charts or tables. The effect of altitude on the coefficient of heat transfer can only be determined by test. It is not too unlikely that the variation of the coefficient of heat transfer will closely parallel the variation of density for a constant velocity. As density decreases, Reynolds[1] number decreases and unless the flow regime in the vicinity of the drop is completely turbulent, this will result in an increase in the thickness of the boundary layer, which in turn will impede the transfer of heat. This is another way of saying, that the coefficient of heat transfer will decrease. If, on the other hand, the flow regime is completely turbulent, the coefficient of heat transfer will be more nearly constant and the effect of reduced density will not be counteracted and we should expect improved performance at altitude.

Obviously, most of the above is conjecture. While it is desirable to have experimental confirmation of any hypothesis, it has not yet been shown that the cost of a research program in this case would be justified by anticipated savings which might accrue to more accurate selections.

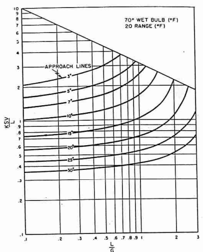

Fig. 2 Chart for selection of L/G for given set of conditions

COUNTERFLOW TOWERS FOR WATER-COOLING DUTY

Contrasting with the dearth of published information concerning the methods of rating air washers for humidification at altitude, there are numerous, albeit conflicting, statements regarding the rating of cooling towers at altitude. Let us quickly note, however, that there seems to be general agreement regarding the significant increase in driving force or enthalpy potential at high elevations over that at sea level. Differences of opinion do exist regarding the extent to which the decrease in mass air flow offsets the increase in driving force at altitude.

Correspondence from one manufacturer states emphatically that he does *not* derate evaporative type equipment for the effect of altitude. All equipment is selected as if it were to perform at sea level, i.e., rating systems are based on sea level test data and psychrometric charts. However, he does point out that he has found it necessary to increase the fan horsepower to the sea level value to obtain equal thermal performance for the same size tower. This manufacturer claims performance tests at various altitudes substantiate the correctness of his approach.

Another manufacturer publishes a statement to the effect that tower selections based on sea level data will be slightly conservative in size or horsepower or both, if the installation is for an altitude greater than 3000 ft above sea level. This manufacturer also claims to have a simplified method for converting a required perform-

74 25

One
Method

altitude.

Correspondence from one manufacturer states emphatically that he does *not* derate evaporative type equipment for the effect of altitude. All equipment is selected as if it were to perform at sea level, i.e., rating systems are based on sea level test data and psychrometric charts. However, he does point out that he has found it neces-

Cooling Towers (page 2)

- Increased capacity factor due to increased enthalpy at higher altitudes is more pronounced at higher entering wet-bulb temperature.
- Per one manufacturer's representative, 1/2% per 1000 ft. for 65F EWB and 1.25% per 1000 ft. for 78°F EWB.

Cooling Towers (page 3)

- What about much lower EWB, such as hydronic economizer applications???
- Lower density overpowers the added capacity from increased vapor pressure at higher altitude

Summary

- Use Mfg data where available, BUT check it to be sure reasonable
- Consider
  - ❖density
  - ❖Heat transfer
  - ❖Motor cooling
  - ❖Vapor pressure
  - ❖Mass flow
- Be aware of counteracting factors
- Use altitude psych charts
- Be sure of the altitude for data
- Use absolute barometric pres.

Questions?

Reference Material:

ALTITUDE CORRECTIONS

ALTITUDE FEET	BAROMETER INCHES MERCURY	BAROMETER LBS/SQ IN ATMOS.	SPECIFIC VOLUME CU FT PER LB	REL DEN SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	29.92	14.7	13.340	1.000	.0750	1.080	1.000
100	29.81	14.64	13.389	.996	.0747	1.076	1.004
200	29.70	14.58	13.439	.993	.0745	1.073	1.007
300	29.60	14.52	13.488	.989	.0742	1.068	1.011
400	29.49	14.46	13.538	.985	.0739	1.064	1.015
500	29.38	14.40	13.587	.981	.0736	1.060	1.019
600	29.28	14.36	13.636	.978	.0734	1.057	1.022
700	29.17	14.32	13.686	.975	.0731	1.053	1.026
800	29.06	14.28	13.735	.971	.0728	1.048	1.030
900	28.96	14.24	13.785	.967	.0725	1.044	1.034
1000	28.85	14.20	13.834	.964	.0723	1.041	1.037
1100	28.75	14.14	13.883	.960	.0720	1.037	1.041
1200	28.65	14.08	13.933	.957	.0818	1.034	1.045
1300	28.54	14.02	13.982	.954	.0716	1.031	1.049
1400	28.44	13.96	14.031	.951	.0713	1.027	1.052
1500	28.33	13.90	14.081	.947	.0710	1.022	1.056
1600	28.23	13.86	14.130	.944	.0708	1.020	1.060
1700	28.13	13.82	14.179	.940	.0705	1.015	1.064
1800	28.02	13.78	14.228	.936	.0702	1.011	1.068
1900	27.92	13.74	14.278	.933	.0700	1.008	1.071
2000	27.82	13.70	14.327	.930	.0698	1.005	1.075
2100	27.72	13.64	14.363	.926	.0695	1.001	1.079
2200	27.62	13.58	14.399	.923	.0692	.995	1.083
2300	27.52	13.52	14.435	.920	.0690	.994	1.087
2400	27.41	13.46	14.471	.916	.0687	.989	1.092
2500	27.31	13.40	14.507	.913	.0685	.986	1.096
2600	27.21	13.36	14.543	.909	.0682	.982	1.100
2700	27.11	13.32	14.579	.906	.0680	.979	1.104
2800	27.01	13.28	14.615	.903	.0677	.975	1.108
2900	26.91	13.24	14.651	.900	.0675	.972	1.112
3000	26.81	13.20	14.687	.896	.0672	.968	1.116
3200	26.61	13.10	14.836	.889	.0667	.960	1.124
3400	26.42	13.00	14.986	.883	.0662	.953	1.133
3600	26.23	12.90	15.135	.877	.0658	.948	1.141
3800	26.03	12.80	15.285	.870	.0653	.940	1.149
4000	25.84	12.70	15.434	.864	.0648	.933	1.157
4200	25.65	12.60	15.554	.858	.0644	.927	1.166
4400	25.46	12.50	15.674	.851	.0638	.919	1.175
4600	25.27	12.40	15.795	.845	.0634	.913	1.184
4800	25.08	12.30	15.915	.839	.0629	.906	1.193
5000	24.89	12.20	16.035	.832	.0624	.899	1.202
5200	24.71	12.12	16.167	.825	.0619	.891	1.212
5400	24.52	12.04	16.299	.819	.0614	.884	1.222
5600	24.34	11.96	16.431	.813	.0610	.878	1.232
5800	24.16	11.88	16.563	.807	.0605	.871	1.242
6000	23.98	11.80	16.695	.799	.0599	.863	1.252
6200	23.80	11.70	16.803	.794	.0596	.858	1.260
6400	23.62	11.60	16.911	.789	.0592	.852	1.268
6600	23.45	11.50	17.018	.784	.0588	.847	1.276
6800	23.27	11.40	17.126	.779	.0584	.841	1.284
7000	23.09	11.30	17.234	.774	.0581	.835	1.292
7200	22.90	11.22	17.397	.767	.0575	.828	1.304
7400	22.70	11.14	17.560	.760	.0570	.821	1.316
7600	22.51	11.06	17.724	.753	.0565	.814	1.329
7800	22.31	10.98	17.887	.746	.0560	.806	1.341
8000	22.12	10.90	18.050	.739	.0554	.798	1.353
8200	21.97	10.82	18.171	.734	.0551	.793	1.362
8400	21.82	10.74	18.293	.729	.0547	.788	1.371
8600	21.68	10.66	18.414	.725	.0544	.783	1.380
8800	21.53	10.58	18.536	.720	.0540	.778	1.390
9000	21.38	10.50	18.657	.715	.0536	.772	1.399
9200	21.22	10.42	18.809	.709	.0532	.766	1.410
9400	21.06	10.34	18.961	.704	.0528	.760	1.421
9600	20.89	10.26	19.114	.698	.0524	.755	1.433
9800	20.73	10.18	19.265	.693	.0520	.749	1.444
10000	20.57	10.10	19.418	.687	.0515	.742	1.456

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ALTITUDE CORRECTIONS

ALTITUDE FEET	BAROMETER INCHES MERCURY	BAROMETER LBS/SQ IN ATMOS.	SPECIFIC VOLUME CU FT PER LB	REL DEN SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	29.92	14.7	13.340	1.000	.0750	1.080	1.000
100	29.81	14.64	13.389	.996	.0747	1.076	1.004
200	29.70	14.58	13.439	.993	.0745	1.073	1.007
300	29.60	14.52	13.488	.989	.0742	1.068	1.011
400	29.49	14.46	13.538	.985	.0739	1.064	1.015
500	29.38	14.40	13.587	.981	.0736	1.060	1.019
600	29.28	14.36	13.636	.978	.0734	1.057	1.022
700	29.17	14.32	13.686	.975	.0731	1.053	1.026
800	29.06	14.28	13.735	.971	.0728	1.048	1.030
900	28.96	14.24	13.785	.967	.0725	1.044	1.034
1000	28.85	14.20	13.834	.964	.0723	1.041	1.037
1100	28.75	14.14	13.883	.960	.0720	1.037	1.041
1200	28.65	14.08	13.933	.957	.0818	1.034	1.045
1300	28.54	14.02	13.982	.954	.0716	1.031	1.049
1400	28.44	13.96	14.031	.951	.0713	1.027	1.052
1500	28.33	13.90	14.081	.947	.0710	1.022	1.056
1600	28.23	13.86	14.130	.944	.0708	1.020	1.060
1700	28.13	13.82	14.179	.940	.0705	1.015	1.064
1800	28.02	13.78	14.228	.936	.0702	1.011	1.068
1900	27.92	13.74	14.278	.933	.0700	1.008	1.071
2000	27.82	13.70	14.327	.930	.0698	1.005	1.075
2100	27.72	13.64	14.363	.926	.0695	1.001	1.079
2200	27.62	13.58	14.399	.923	.0692	.995	1.083
2300	27.52	13.52	14.435	.920	.0690	.994	1.087
2400	27.41	13.46	14.471	.916	.0687	.989	1.092
2500	27.31	13.40	14.507	.913	.0685	.986	1.096
2600	27.21	13.36	14.543	.909	.0682	.982	1.100
2700	27.11	13.32	14.579	.906	.0680	.979	1.104
2800	27.01	13.28	14.615	.903	.0677	.975	1.108
2900	26.91	13.24	14.651	.900	.0675	.972	1.112
3000	26.81	13.20	14.687	.896	.0672	.968	1.116
3200	26.61	13.10	14.836	.889	.0667	.960	1.124
3400	26.42	13.00	14.986	.883	.0662	.953	1.133
3600	26.23	12.90	15.135	.877	.0658	.948	1.141
3800	26.03	12.80	15.285	.870	.0653	.940	1.149
4000	25.84	12.70	15.434	.864	.0648	.933	1.157
4200	25.65	12.60	15.554	.858	.0644	.927	1.166
4400	25.46	12.50	15.674	.851	.0638	.919	1.175
4600	25.27	12.40	15.795	.845	.0634	.913	1.184
4800	25.08	12.30	15.915	.839	.0629	.906	1.193
5000	24.89	12.20	16.035	.832	.0624	.899	1.202
5200	24.71	12.12	16.167	.825	.0619	.891	1.212
5400	24.52	12.04	16.299	.819	.0614	.884	1.222
5600	24.34	11.96	16.431	.813	.0610	.878	1.232
5800	24.16	11.88	16.563	.807	.0605	.871	1.242
6000	23.98	11.80	16.695	.799	.0599	.863	1.252
6200	23.80	11.70	16.803	.794	.0596	.858	1.260
6400	23.62	11.60	16.911	.789	.0592	.852	1.268
6600	23.45	11.50	17.018	.784	.0588	.847	1.276
6800	23.27	11.40	17.126	.779	.0584	.841	1.284
7000	23.09	11.30	17.234	.774	.0581	.835	1.292
7200	22.90	11.22	17.397	.767	.0575	.828	1.304
7400	22.70	11.14	17.560	.760	.0570	.821	1.316
7600	22.51	11.06	17.724	.753	.0565	.814	1.329
7800	22.31	10.98	17.887	.746	.0560	.806	1.341
8000	22.12	10.90	18.050	.739	.0554	.798	1.353
8200	21.97	10.82	18.171	.734	.0551	.793	1.362
8400	21.82	10.74	18.293	.729	.0547	.788	1.371
8600	21.68	10.66	18.414	.725	.0544	.783	1.380
8800	21.53	10.58	18.536	.720	.0540	.778	1.390
9000	21.38	10.50	18.657	.715	.0536	.772	1.399
9200	21.22	10.42	18.809	.709	.0532	.766	1.410
9400	21.06	10.34	18.961	.704	.0528	.760	1.421
9600	20.89	10.26	19.114	.698	.0524	.755	1.433
9800	20.73	10.18	19.265	.693	.0520	.749	1.444
10000	20.57	10.10	19.418	.687	.0515	.742	1.456

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ALTITUDE CORRECTIONS

ALTITUDE FEET	BAROMETER INCHES MERCURY	BAROMETER LBS/SQ IN ATMOS.	SPECIFIC VOLUME CU FT PER LB	REL DEN SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	29.92	14.7	13.340	1.000	.0750	1.080	1.000
100	29.81	14.64	13.389	.996	.0747	1.076	1.004
200	29.70	14.58	13.439	.993	.0745	1.073	1.007
300	29.60	14.52	13.488	.989	.0742	1.068	1.011
400	29.49	14.46	13.538	.985	.0739	1.064	1.015
500	29.38	14.40	13.587	.981	.0736	1.060	1.019
600	29.28	14.36	13.636	.978	.0734	1.057	1.022
700	29.17	14.32	13.686	.975	.0731	1.053	1.026
800	29.06	14.28	13.735	.971	.0728	1.048	1.030
900	28.96	14.24	13.785	.967	.0725	1.044	1.034
1000	28.85	14.20	13.834	.964	.0723	1.041	1.037
1100	28.75	14.14	13.883	.960	.0720	1.037	1.041
1200	28.65	14.08	13.933	.957	.0818	1.034	1.045
1300	28.54	14.02	13.982	.954	.0716	1.031	1.049
1400	28.44	13.96	14.031	.951	.0713	1.027	1.052
1500	28.33	13.90	14.081	.947	.0710	1.022	1.056
1600	28.23	13.86	14.130	.944	.0708	1.020	1.060
1700	28.13	13.82	14.179	.940	.0705	1.015	1.064
1800	28.02	13.78	14.228	.936	.0702	1.011	1.068
1900	27.92	13.74	14.278	.933	.0700	1.008	1.071
2000	27.82	13.70	14.327	.930	.0698	1.005	1.075
2100	27.72	13.64	14.363	.926	.0695	1.001	1.079
2200	27.62	13.58	14.399	.923	.0692	.995	1.083
2300	27.52	13.52	14.435	.920	.0690	.994	1.087
2400	27.41	13.46	14.471	.916	.0687	.989	1.092
2500	27.31	13.40	14.507	.913	.0685	.986	1.096
2600	27.21	13.36	14.543	.909	.0682	.982	1.100
2700	27.11	13.32	14.579	.906	.0680	.979	1.104
2800	27.01	13.28	14.615	.903	.0677	.975	1.108
2900	26.91	13.24	14.651	.900	.0675	.972	1.112
3000	26.81	13.20	14.687	.896	.0672	.968	1.116
3200	26.61	13.10	14.836	.889	.0667	.960	1.124
3400	26.42	13.00	14.986	.883	.0662	.953	1.133
3600	26.23	12.90	15.135	.877	.0658	.948	1.141
3800	26.03	12.80	15.285	.870	.0653	.940	1.149
4000	25.84	12.70	15.434	.864	.0648	.933	1.157
4200	25.65	12.60	15.554	.858	.0644	.927	1.166
4400	25.46	12.50	15.674	.851	.0638	.919	1.175
4600	25.27	12.40	15.795	.845	.0634	.913	1.184
4800	25.08	12.30	15.915	.839	.0629	.906	1.193
5000	24.89	12.20	16.035	.832	.0624	.899	1.202
5200	24.71	12.12	16.167	.825	.0619	.891	1.212
5400	24.52	12.04	16.299	.819	.0614	.884	1.222
5600	24.34	11.96	16.431	.813	.0610	.878	1.232
5800	24.16	11.88	16.563	.807	.0605	.871	1.242
6000	23.98	11.80	16.695	.799	.0599	.863	1.252
6200	23.80	11.70	16.803	.794	.0596	.858	1.260
6400	23.62	11.60	16.911	.789	.0592	.852	1.268
6600	23.45	11.50	17.018	.784	.0588	.847	1.276
6800	23.27	11.40	17.126	.779	.0584	.841	1.284
7000	23.09	11.30	17.234	.774	.0581	.835	1.292
7200	22.90	11.22	17.397	.767	.0575	.828	1.304
7400	22.70	11.14	17.560	.760	.0570	.821	1.316
7600	22.51	11.06	17.724	.753	.0565	.814	1.329
7800	22.31	10.98	17.887	.746	.0560	.806	1.341
8000	22.12	10.90	18.050	.739	.0554	.798	1.353
8200	21.97	10.82	18.171	.734	.0551	.793	1.362
8400	21.82	10.74	18.293	.729	.0547	.788	1.371
8600	21.68	10.66	18.414	.725	.0544	.783	1.380
8800	21.53	10.58	18.536	.720	.0540	.778	1.390
9000	21.38	10.50	18.657	.715	.0536	.772	1.399
9200	21.22	10.42	18.809	.709	.0532	.766	1.410
9400	21.06	10.34	18.961	.704	.0528	.760	1.421
9600	20.89	10.26	19.114	.698	.0524	.755	1.433
9800	20.73	10.18	19.265	.693	.0520	.749	1.444
10000	20.57	10.10	19.418	.687	.0515	.742	1.456

ORRECTIONS

REL DEN / SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
1.000	.0750	1.080	1.000
.996	.0747	1.076	1.004
.993	.0745	1.073	1.007
.989	.0742	1.068	1.011
.985	.0739	1.064	1.015
.981	.0736	1.060	1.019
.978	.0734	1.057	1.022
.975	.0731	1.053	1.026
.971	.0728	1.048	1.030
.967	.0725	1.044	1.034
.964	.0723	1.041	1.037
.960	.0720	1.037	1.041
.957	.0818	1.034	1.045

ALTITUDE CO

ALTITUDE FEET	BAROMETER INCHES MERCURY	BAROMETER LBS/SQ IN ATMOS.	SPECIFIC VOLUME CU FT PER LB
0	29.92	14.7	13.340
100	29.81	14.64	13.389
200	29.70	14.58	13.439
300	29.60	14.52	13.488
400	29.49	14.46	13.538
500	29.38	14.40	13.587
600	29.28	14.36	13.636
700	29.17	14.32	13.686
800	29.06	14.28	13.735
900	28.96	14.24	13.785
1000	28.85	14.20	13.834
1100	28.75	14.14	13.883
1200	28.65	14.08	13.933
1300	28.54	14.02	13.982
1400	28.44	13.96	14.031

Performance Adjustment Factors (Cont.)

GLYCOL AND PERFORMANCE ADJUSTMENT FACTORS

Table 18-1 — Performance Adjustment Factors (20-60 Ton Units Only)

Fouling Factor	Chilled Water ΔT	Sea Level CAP	Sea Level GPM	Sea Level KW	2,000 Feet CAP	2,000 Feet GPM	2,000 Feet KW	4,000 Feet CAP	4,000 Feet GPM	4,000 Feet KW	6,000 Feet CAP	6,000 Feet GPM	6,000 Feet KW
0.00025	6	0.987	1.650	0.993	0.967	1.640	1.003	0.952	1.620	1.019	0.932	1.570	1.029
	8	0.993	1.250	0.997	0.973	1.240	1.007	0.956	1.220	1.025	0.935	1.190	1.035
	10	1.000	1.000	1.000	0.980	0.990	1.010	0.960	0.970	1.030	0.940	0.940	1.040
	12	1.007	0.820	1.003	0.987	0.810	1.013	0.966	0.800	1.035	0.945	0.780	1.045
	14	1.013	0.710	1.007	0.993	0.700	1.017	0.972	0.680	1.038	0.952	0.660	1.048
	16	1.020	0.640	1.010	1.000	0.630	1.020	0.980	0.620	1.040	0.960	0.600	1.050
0.001	6	0.957	1.615	0.979	0.953	1.600	0.989	0.931	1.570	0.990	0.914	1.540	1.002
	8	0.964	1.215	0.982	0.959	1.210	0.992	0.937	1.180	0.994	0.920	1.170	1.006
	10	0.970	0.965	0.985	0.964	0.960	0.995	0.943	0.940	0.998	0.926	0.920	1.009
	12	0.976	0.785	0.989	0.966	0.790	0.998	0.945	0.770	1.007	0.926	0.760	1.018
	14	0.982	0.675	0.993	0.968	0.670	1.001	0.947	0.650	1.016	0.927	0.640	1.027
	16	0.989	0.620	0.996	0.970	0.600	1.004	0.949	0.590	1.025	0.927	0.580	1.036
0.002	6	0.916	1.565	0.951	0.913	1.550	0.969	0.896	1.490	0.975	0.871	1.450	0.984
	8	0.923	1.245	0.958	0.919	1.170	0.972	0.898	1.110	0.979	0.874	1.080	0.987
	10	0.930	0.925	0.965	0.925	0.920	0.975	0.900	0.890	0.982	0.877	0.880	0.989
	12	0.934	0.810	0.969	0.927	0.750	0.978	0.908	0.730	0.986	0.885	0.720	0.993
	14	0.938	0.695	0.973	0.929	0.640	0.981	0.916	0.620	0.989	0.894	0.610	0.997
	16	0.948	0.580	0.976	0.931	0.580	0.983	0.924	0.580	0.993	0.902	0.570	1.001

Table 18-2 — Performance Adjustment Factors (10 & 15 Ton Units Only)

Fouling Factor	Chilled Water ΔT	Sea Level CAP	Sea Level GPM	Sea Level KW	2,000 Feet CAP	2,000 Feet GPM	2,000 Feet KW	4,000 Feet CAP	4,000 Feet GPM	4,000 Feet KW	6,000 Feet CAP	6,000 Feet GPM	6,000 Feet KW
0.00025	6	1.00	1.66	1.00	0.98	1.63	1.01	0.95	1.59	1.02	0.93	1.54	1.05
	8	1.00	1.25	1.00	0.98	1.22	1.01	0.96	1.19	1.02	0.93	1.16	1.05
	10	1.00	1.00	1.00	0.98	0.98	1.01	0.95	0.95	1.02	0.92	0.92	1.04
	12	1.00	0.83	1.00	0.98	0.81	1.01	0.95	0.79	1.02	0.92	0.77	1.04
	14	0.99	0.71	1.00	0.97	0.59	1.01	0.95	0.68	1.02	0.92	0.66	1.04
0.001	6	0.96	1.60	0.98	0.94	1.57	0.99	0.92	1.53	1.00	0.90	1.49	1.01
	8	0.96	1.20	0.98	0.94	1.18	0.99	0.92	1.15	1.00	0.90	1.12	1.01
	10	0.96	0.96	0.98	0.94	0.94	0.99	0.92	0.92	1.00	0.89	0.89	1.01
	12	0.96	0.80	0.98	0.94	0.79	0.99	0.92	0.77	1.00	0.89	0.74	1.01
	14	0.96	0.68	0.98	0.94	0.67	0.99	0.92	0.65	1.00	0.89	0.66	1.01
0.002	8	0.93	1.15	0.95	0.91	1.13	0.96	0.88	1.10	0.98	0.86	1.07	0.99
	10	0.90	0.90	0.94	0.89	0.88	0.95	0.87	0.87	0.96	0.85	0.84	0.98
	12	0.90	0.75	0.94	0.88	0.73	0.95	0.86	0.72	0.95	0.84	0.70	0.98
	14	0.90	0.64	0.94	0.87	0.63	0.95	0.86	0.82	0.95	0.84	0.60	0.98

*Standard chilled water Δ is 8-12 for CGA 120-180.
Standard chilled water Δ is 6-16 for CGAE 20-60.

obtain the BHP at 600°F. If the rating table showed 30.0 BHP, the actual would be 30.0 (530/1060) = 15.0 BHP.

It often happens that a fan, at startup, will handle cold air, and after running for a period will handle hot air. Such might be the case in an oven exhaust system. If **Example 2** were such a case, the fan would require 30.0 BHP when operating at 70°F., and 15.0 BHP when the oven had warmed to 600°F. Very often a damper is furnished with the fan so that, during the warming-up period, the fan can be dampered to reduce the horsepower. Without the damper, a 30 HP motor would be needed. If the warm-up period lasts only a couple of minutes, a motor half-way between hot and cold horsepower requirements could be selected.

Confusion may be avoided by specifying at what temperature the static pressure was calculated. In **Example 2,** the specifications should read either:

"11,000 CFM and 6"SP at 600°F." <u>or</u>
"11,000 CFM for operation at 600°F and 12"SP at 70°F."

Table 1 gives correction factors to use to convert from the density of non-standard temperature air to the density of 70°F. air. These factors are merely the ratios of absolute temperatures. Dividing static pressure and brake horsepower at 70°F. by the factor for a particular temperature will give the static pressure and brake horsepower at that temperature.

Table 1
CORRECTIONS FOR TEMPERATURE

Air Temp., Deg. F.	Factor	Air Temp., Deg. F.	Factor
−50	0.77	275	1.39
−25	0.82	300	1.43
0	0.87	325	1.48
+20	0.91	350	1.53
40	0.94	375	1.58
60	0.98	400	1.62
70	1.00	450	1.72
80	1.02	500	1.81
100	1.06	550	1.91
120	1.09	600	2.00
140	1.13	650	2.10
160	1.17	700	2.19
180	1.21	750	2.28
200	1.25	800	2.38
225	1.29	900	2.56
250	1.34	1000	2.76

At the end of this article, the factors that determine the best location for the fan in a hot process system are discussed.

<u>How to Calculate Actual Fan Performance at Other Than Sea Level</u>

When a fan operates at some altitude above sea level, it handles air less dense than standard. This is similar to the case of the fan handling high temperature air, since in both cases the air is less dense than standard. **Table 2** gives the ratio of standard air density at sea level to densities at 70°F. at other altitudes.

Table 2
CORRECTIONS FOR ALTITUDE

Altitude, Ft. Above Sea Level	Factor	Altitude, Ft. Above Sea Level	Factor
0	1.00	5000	1.20
500	1.02	5500	1.22
1000	1.04	6000	1.25
1500	1.06	6500	1.27
2000	1.08	7000	1.30
2500	1.10	7500	1.32
3000	1.12	8000	1.35
3500	1.14	8500	1.37
4000	1.16	9000	1.40
4500	1.18	10000	1.45

Example 3. Required: 5800 CFM at 6"SP at 5000 ft. altitude. Air at sea level weighs 1.20 times as much as air at 5000 ft.; therefore, sea level SP = 1.20 x 6 = 7.20"SP. Select a fan for 5800 CFM at 7.20"SP and divide the rating table brake horsepower at 1.20.

Where both heat and altitude are combined, the air is rarified by each, independently, so that the factors that are to be used can be multiplied together.

Example 4. Required: 5800 CFM at 6"SP at 600°F. at 5000 ft. altitude. Air at 70°F. at sea level weighs 2.00 x 1.20 = 2.40 times as much as air at 600°F., 5000 ft. altitude. At sea level and 70°F., SP = 2.40 x 6 = 14.4"SP. Select a fan for 5800 CFM at 14.4"SP. Divide the brake horsepower in the rating table by 2.40 to obtain horsepower at 600°F. and 5000 ft. If the fan is to start cold, it will still be at 5000 ft. altitude. Therefore, to get the "cold" horsepower requirement, divide by 1.20, the altitude factor, only.

<u>Density Changes From Other Than Heat and Altitude</u>

Fan densities may vary from standard for other reasons than heat and altitude. Moisture, gas (other than air) or mixtures of gases are only a few possibilities. In these cases it is necessary to obtain the actual density of the inlet gas by some other reference material. A similar factor, as shown in **Table 1,** is then created as the standard density .075 lb. per cubic inch divided by the new density.

$$\text{Factor} = \frac{.075}{\text{special gas density}}$$

Elevation

An additional factor that affects the motor's ability to dissipate heat is the density of the surrounding air. With higher air density, more heat can be transferred. Generally the density of air at a specific location is very constant, but air density does vary with elevation; thus, when motors are installed at locations where the elevation is substantially above sea level, consideration must be given to this factor.

Standard motors will operate successfully within their normal temperature rating at elevations up to 1000 meters (3300 ft.) above sea level. When motors are to be operated above this altitude, the motor design should be checked for its suitability at the required elevation. Contact WMC Round Rock for evaluation. When required, motor designs can be modified to make them suitable for high elevation operation.

Altitude (feet)	**HP Derating Factor**
3,300-5,000	0.97
5,001-6,600	0.94
6,601-8,300	0.90
8,301-9,900	0.86
9,901-11,500	0.82

difference between the highest and lowest peak amplitudes of the current pulses over one cycle exceed 10 percent of the highest pulse amplitude at rated armature current.

e. Low noise levels are required.

3. Operation at speeds above the highest rated speed.
4. Operation in a poorly ventilated room, in a pit, or in an inclined position.
5. Operation where subjected to:
   a. Torsional impact loads.
   b. Repetitive abnormal overloads.
   c. Reversing or electric braking.
6. Operation of machine at standstill with any winding continuously energized or of short-time rated machine with any winding continuously energized.
7. Operation of direct-current machine where the average armature current is less than 50 percent of the rated full-load amperes over a 24-hour period, or continuous operation at armature current less than 50 percent of rated current for more than 4 hours.

Authorized Engineering Information 10-27-1926, revised 11-11-1965; 11-16-1967; 7-15-1970; 1-25-1972; 11-8-1973; 3-14-1979.

MG 1-14.04 Operation at Altitudes Above 3300 Feet (1000 Meters)

The temperature rises given for motors and generators in MG 1-12.41, MG 1-12.42, MG 1-12.62 and MG 1-15.41 are based upon operation at altitudes of 3300 feet (1000 meters) or less and a maximum ambient temperature of 40°C. It is also recognized as good practice to use motors and generators at altitudes greater than 3300 feet (1000 meters) as indicated in the following paragraphs:

A. Motors and generators having Class A or B insulation systems and temperature rises in accordance with MG 1-12.41, MG 1-12.42, MG 1-12.62 and MG 1-15.41 will operate satisfactorily at altitudes above 3300 feet (1000 meters) in those locations where the decrease in ambient temperature compensates for the increase in temperature rise, as follows:

Ambient Temperature, Degrees C	Maximum Altitude, Feet (Meters)
40	3300 (1000)
30	6600 (2000)
20	9900 (3000)

B. Motors having a service factor of 1.15 or higher will operate satisfactorily at unity service factor at an ambient temperature of 40°C at altitudes above 3300 feet (1000 meters) up to 9000 feet (2740 meters).

C. Motors and generators which are intended for use at altitudes above 3300 feet (1000 meters) at an ambient temperature of 40°C should have temperature rises at sea level not exceeding the values calculated from the following formula:

When altitude in feet:

$$T_{RSL} = T_{RA}\left[1 - \frac{(\text{Alt} - 3300)}{33000}\right]$$

—or—

When altitude in meters:

$$T_{RSL} = T_{RA}\left[1 - \frac{(\text{Alt} - 1000)}{10000}\right]$$

where:

T_{RSL} = test temperature rise in degrees C at sea level.
T_{RA} = temperature rise in degrees C from the appropriate table in MG 1-12.41, MG 1-12.42, MG 1-12.62 or MG 1-15.41.
Alt = altitude above sea level in feet (meters) at which machine is to be operated.

D. Preferred values of altitude are 3300 feet (1000 meters), 6600 feet (2000 meters), 9900 feet (3000 meters), 13200 feet (4000 meters) and 16500 feet (5000 meters).

Authorized Engineering Information 11-12-1964.

MG 1-14.05 Short-time Rated Electrical Machines

Short-time rated electrical machines (see MG 1-10.35 and MG 1-10.63) should be applied so as to insure performance without injury. They should not be used (except on the recommendation of the manufacturer) on any application where the driven machine may be left running continuously.

NEMA Standard 10-29-1937.

MG 1-14.06 Direction of Rotation

Facing the end of the machine opposite the drive, the standard direction of rotation for all nonreversing direct-current motors, all alternating-current single-phase motors, all synchronous motors and all universal motors shall be counterclockwise. For alternating- and direct-current generators, the rotation shall be clockwise. Where two or more machines are mechanically coupled together, this standard may not apply to all units.

NEMA Standard 1-26-1934.

NOTE—This does not apply to polyphase induction motors as most applications on which they are used are of such a nature that either or both directions of rotation may be required, and the phase sequence of the power lines is rarely known.

Authorized Engineering Information 1-26-1934.

NET POSITIVE SUCTION HEAD

(NPSH)

NPSH combines all of the factors limiting the suction side of a pump; internal pump losses, static suction lift, friction losses, vapor pressure and atmospheric conditions. It is important to differentiate between Required NPSH and Available NPSH.

Required NPSH - this refers to internal pump losses and is determined by laboratory test. It varies with each pump and with each pump capacity and speed change. The greater the capacity, the greater the required NPSH. Required NPSH must always be given by the pump manufacturer.

Available NPSH - this is a characteristic of the system. It can be calculated, or on an existing installation, it can be determined by field test using vacuum and pressure gauges. By definition, it is the net positive suction head above the vapor pressure available at the suction flange of the pump to maintain a liquid state. Since there are also internal pump losses (required NPSH) the available NPSH in a system must exceed the pump required NPSH -- otherwise, reduction in capacity, loss of efficiency, noise, vibration and cavitation will result.

NPSH FORMULAS

PROPOSED INSTALLATION

To calculate the N. P. S. H. available in a proposed application, the following formula is recommended:

$$Hsv = Hp \pm Hz - Hf - Hvp$$

Hsv = Available N. P. S. H. expressed in feet of fluid.

Hp = Absolute pressure on the surface of the liquid where the pump takes suction, expressed in "feet". This could be atmospheric pressure or vessel pressure (pressurized tank).

Hz = Static elevation of the liquid above, or below the centerline of the impeller, expressed in feet.

Hf = Friction and velocity head loss in the piping, also expressed in feet.

Hvp = Absolute vapor pressure of the fluid at the pumping temperature, expressed in feet of fluid.

and to overcome the pump internal pressure losses is the *required NPSH* of the pump.

The required NPSH of a pump is part of the standard design performance data furnished by the manufacturer or of a design specific to a given process pump.

The net positive suction head (pressure in feet of liquid) of the process liquid system as it exists within the system complex at the entering (suction) side of the pump is called the *available NPSH*. It must be at least equal to or greater than the required NPSH in order to produce a flow thru a pump. A safety factor should be considered to cover a possible excess of required NPSH.

The available NPSH is the algebraic sum determined by the formula:

$$\text{Available NPSH} = \frac{2.31\ (P_a - P_{vp})}{\text{sp gr}} + H_s - H_f$$

where:

NPSH = net positive suction head (absolute pressure, ft)

2.31 = conversion factor to change one pound pressure at a specific gravity of 1.0 to pressure head in feet of water (1 inch Hg = 1.134 ft of water).

P_a = atmospheric pressure (absolute pressure, psia) in an open system; or pressure (absolute, psia) within a totally closed system.

P_{vp} = vapor pressure (psia) of the fluid at pumping temperature; in a totally closed system it is part of the total pressure P_a.

H_s = elevation head, static head (ft) above or below the pump center line. If above, positive static head; if below, negative static head, sometimes termed suction lift.*

H_f = friction head (ft) on the suction side of the system including piping, fittings, valves, heat exchangers at the design velocity (V_s in ft per sec) within suction system.

sp gr = specific gravity of liquid handled at operating temperature (Fig. 14).

Figures 11 and 12 illustrate the application of the calculation of available NPSH to the variety of open and closed circuits. Three additional terms are introduced in these figures:

H_{vp} = vapor pressure (ft) of the fluid at pumping temperature.

H_e = entrance head (ft), suction pipe entrance loss in open systems.

$H_{V_{se}}$ = pump suction eye velocity head (ft), $(V_{se})^2/2g$. This term is usually very small as shown in the following tabulation:

Velocity (ft/sec)	3	4	5	6	7
Velocity head (ft)	.14	.25	.39	.56	.76
Velocity (ft/sec)	8	9	10	11	12
Velocity head (ft)	.99	1.26	1.55	1.88	2.23

[redacted]

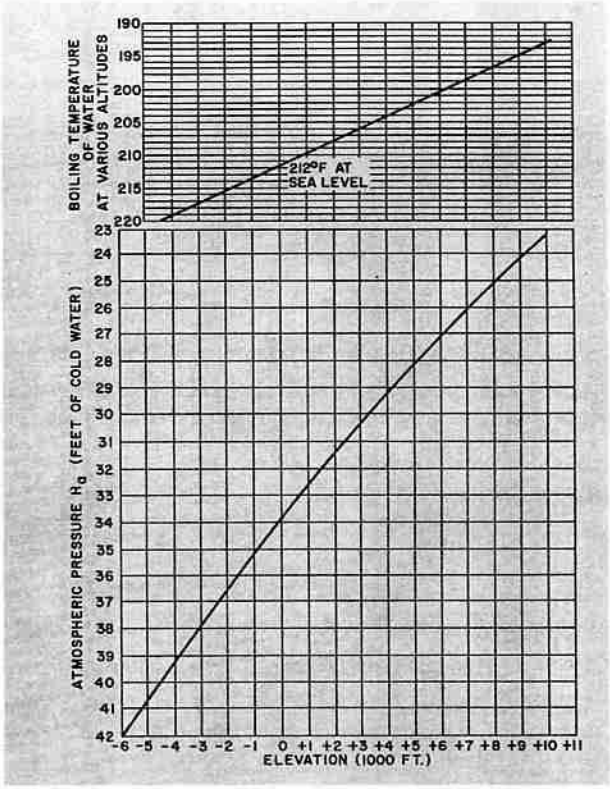

FIG. 13 — EFFECT OF ALTITUDE ON ATMOSPHERIC PRESSURE

A pressure selected to be maintained above atmospheric pressure in the top circuit of a closed piping system determines the design $H_{(expansion\ tanks)}$ pressure *(Fig. 12)*.

On examining *Fig. 11 and 12*, it is evident that the available NPSH may vary, especially with critical fluids. The variables that may be either fixed or adjusted are:

1. Altitude of the system location above or below sea level; *Fig. 13* shows the change of atmospheric pressure (feet of cold water) with the altitude. The greater the altitude, the lower is the available atmospheric pressure (P_a in psia or H_a in ft) which influences an open system. The totally closed system pressure P_a may be regulated.
2. Vapor pressure of the liquid *(Fig. 14)* pumped at operating temperature P_{vp} (psia) or H_{vp} (ft); *Figure 14* shows the vapor pressure of water at various temperatures. This pressure may or may not be adjusted.
3. Friction losses of the pump suction piping system; the larger the pipe, the less are the friction losses H_f (ft) for a given fluid flow.

*It must be remembered that a pump does not lift the liquid it moves; a pump must have pressure to produce the flow.

High altitude effects on the performance of equipment involving water evaporation

ROBERT JORGENSEN
Member ASHRAE

There are many types of heating, refrigerating, and air-conditioning equipment which utilize the psychrometric process of evaporating water into air. These equipment types may be classified in two groups according to whether the main function is to: (1) increase the amount of water vapor in the air, or (2) remove heat from the water. Among the former are various types of humidifiers, air washers, and evaporative air coolers as listed in Chapter 38 of the Guide And Data Book.[1] Among the latter are various types of cooling towers and spray ponds as listed in Chapter 37 of the Guide And Data Book,[1] plus evaporative condensers as described in Chapter 32 of the Guide And Data Book[1] and air washers which may be considered a special form of cooling tower.

The purpose of this paper, like that of all the other papers presented at this Symposium, is to examine the methods of accounting for altitude effect which are in use. Hopefully, this will stimulate interest in improving on these methods and establishing standards. In order to keep this paper from becoming too long, only two types of equipment will be examined, one for each of the above categories. Perhaps as a result of this small start, studies covering all types will be made in the near future.

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AIR WASHERS FOR HUMIDIFYING DUTY

This Task Group was not able to find any published data giving the effect of altitude on the performance of air washers for humidifying duty. An analytical study was, therefore, made.

The Guide And Data Book[1] defines the humidifying effectiveness of a recirculated spray air washer as follows:

$$\eta = \frac{t_E - t_L}{t_E - t'}, \text{ where}$$

η = humidifying efficiency or effectiveness,
t_E = entering dry-bulb temperature,
t_L = leaving dry-bulb temperature, and
t' = entering (and leaving) wet-bulb temperature.

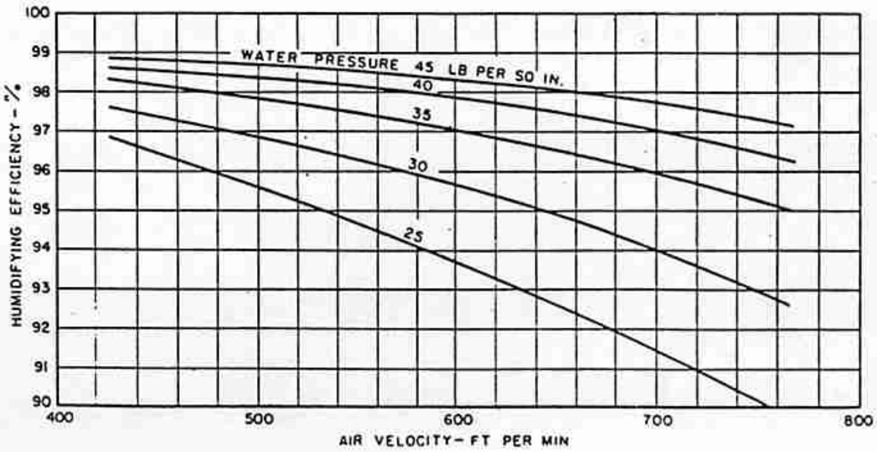

Fig. 1 Effect of air velocity and water pressure on humidifying efficiency

The performance capabilities of an air washer are usually determined from tests on apparatus using recirculated spray water. It has been found that the value of humidifying efficiency or effectiveness for a given type of washer construction varies with air velocity and water pressure, as shown in Fig. 1.

It is this Task Group's belief that most of this type of information is obtained from sea level tests and is used without regard for the altitude of the application. Furthermore, this Task Group is unaware of any complaints about performance at altitude.

A quick comparison of air washers with other mass-transfer equipment suggests that mass velocity, rather than air velocity, is the significant parameter. If it is, then it would be proper to enter Fig. 1 with an equivalent air velocity based on an equal mass velocity. Since the equivalent velocity would be lower than the actual velocity, a higher efficiency would result and this might explain why no complaints have been noted.

The above conclusion can also be reached by noting the effect on efficiency of reducing the density in the following expression and assuming that all other factors are constant:

$$\eta = 1 - e^{-\frac{hS}{cV\delta}} \quad \text{where}$$

η = humidifying efficiency,
e = 2.718,
h = coefficient of heat transfer (air film)
S = interfacial area (between water and air),
c = specific heat (humid),
V = air velocity, and
δ = air density.

It should be observed that while the interfacial area (S) can be considered constant for a given air washer, and the specific heat (c) can be considered independent of altitude, the performance of an air washer at altitude will not equal that at the same air velocity (V) at sea level unless the effects of altitude on the density (δ) and the coefficient of heat transfer (h) are compensating. The effect of altitude on density can be determined from psychrometric charts or tables. The effect of altitude on the coefficient of heat transfer can only be determined by test. It is not too unlikely that the variation of the coefficient of heat transfer will closely parallel the variation of density for a constant velocity. As density decreases, Reynolds[1] number decreases and unless the flow regime in the vicinity of the drop is completely turbulent, this will result in an increase in the thickness of the boundary layer, which in turn will impede the transfer of heat. This is another way of saying, that the coefficient of heat transfer will decrease. If, on the other hand, the flow regime is completely turbulent, the coefficient of heat transfer will be more nearly constant and the effect of reduced density will not be counteracted and we should expect improved performance at altitude.

Obviously, most of the above is conjecture. While it is desirable to have experimental confirmation of any hypothesis, it has not yet been shown that the cost of a research program in this case would be justified by anticipated savings which might accrue to more accurate selections.

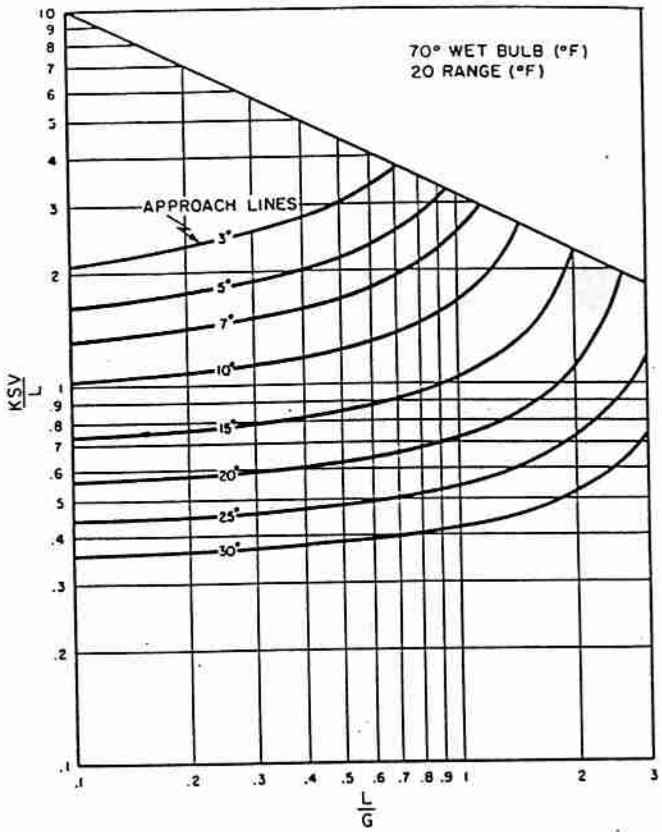

Fig. 2 Chart for selection of L/G for given set of conditions

COUNTERFLOW TOWERS FOR WATER-COOLING DUTY

Contrasting with the dearth of published information concerning the methods of rating air washers for humidification at altitude, there are numerous, albeit conflicting, statements regarding the rating of cooling towers at altitude. Let us quickly note, however, that there seems to be general agreement regarding the significant increase in driving force or enthalpy potential at high elevations over that at sea level. Differences of opinion do exist regarding the extent to which the decrease in mass air flow offsets the increase in driving force at altitude.

Correspondence from one manufacturer states emphatically that he does *not* derate evaporative type equipment for the effect of altitude. All equipment is selected as if it were to perform at sea level, i.e., rating systems are based on sea level test data and psychrometric charts. However, he does point out that he has found it necessary to increase the fan horsepower to the sea level value to obtain equal thermal performance for the same size tower. This manufacturer claims performance tests at various altitudes substantiate the correctness of his approach.

Another manufacturer publishes a statement to the effect that tower selections based on sea level data will be slightly conservative in size or horsepower or both, if the installation is for an altitude greater than 3000 ft above sea level. This manufacturer also claims to have a simplified method for converting a required perform-

Content Type: Q&A

Question:

Do you have any information or design guides that deal with derating cooling tower performance and/or efficiency because of high altitude operation?

Answer:

I submitted your question to Rich Harrison, Chairman of the Performance and Technology Committee of the **Cooling Technology Institute (CTI)**. Here is his very excellent response...

> CTI has published several papers over the years on the effect of altitude on cooling towers. If you look on the CTI website under the **Bibliography of Technical Papers**, you will see the following three listed under Thermal Performance (copies can be purchased through CTI at $10.00 plus postage and handling):
>
> - TP62-04 Effect of Altitude on Cooling Tower Rating and Performance by Thomas H. Hamilton
> - TP82-13 Effect of Altitude on Cooling Tower Design and Testing by George E. McGee
> - TP83-09 Use of CTI Blue Book at Altitude by Robert Fulkerson
>
> Basically there are three effects of altitude:
>
> 1. The energy-holding content in air at higher altitude is greater than at sea level per pound of dry air. For example, a 78 deg F saturated air (78 Wet Bulb and 78 Dry Bulb) at sea level has 41.586 BTU/lb dry air vs 46.374 BTU/lb dry air at 5000 ft altitude, or +11.5%. This means that the same cooling tower could cool a greater amount of water at altitude at the same temperature conditions PER POUND OF DRY AIR. For example, for the conditions of 95 Inlet Temp to 85 Outlet Temp at 78 Wet Bulb, a counterflow cooling tower with 4 ft of 0.75 inch cross-fluted fill material, the equilibrium Liquid-to-Gas ratio at sea level would be about 1.588, or it will cool 1.588 lbs of water per lb of dry air. At 5000 ft altitude this L/G ratio would increase to 1.873 lb water per lb dry air, a 17.9% increase.
> 2. The air is less dense at higher altitude and therefore it takes more cubic feet of air per lb of dry air. The same 78 deg F saturated air at sea level takes 14.010 ft^3/lb dry air vs 16.953 ft^3/lb dry air at 5000 ft altitude, or +21.0%. In a similar manner the density is reduced from 0.0729 lb mixture/ft^3 to 0.0605 lb mixture/ft^3, or 17% less, thereby reducing the air pressure drop (and fan horsepower) through the tower FOR THE SAME AIR FLOW VOLUME.
> 3. The electric fan motors have reduced cooling capability at higher altitudes due to the less dense air. This means that at very high altitudes, you may not be able to load the motor to the full nameplate load and full motor temperature rise. However, a compensating factor is that at altitude, the ambient temperature is normally less than at sea level. Large field erected cooling tower customers may limit the fan motor power to 90% for longevity of the motor, so the reduced motor capability may not be an issue.
>
> Now, what is the bottom line of combining these three factors? The first factor is positive and the second factor is negative on performance. The overall effect is positive and generally small, 3-8% at 5000 ft altitude, but will depend on the actual temperature conditions. Most factory-assembled cooling tower manufacturers do not take advantage of this correction for altitudes below about 3000 feet. Field-erected towers are built to order and will normally take full advantage of the performance gain at altitude.
>
> I might also suggest the CTI ToolKit software which is available to $395 for members and $450 nonmembers which will allow you to generate psychrometric properties at any altitude and characteristic curve determination at any altitude. Detailed ordering information is available on the CTI website.
>
> Lastly, if your question is prompted by a specific tower, ask the manufacturer for their technical information. Alternatively, if your question is prompted by a potential performance problem, request an independent third-party test by one of the five CTI Thermal Test Agencies.

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providing insights for today's hvac system designer

Engineers Newsletter

volume 39–4

Effects of Altitude

on psychrometric calculations and fan selections

For this EN we're pulling from the archives to address a subject that still causes confusion within the industry and continues to be the subject of frequently asked questions. This EN investigates the effects of altitude on psychrometric calculations and fan selections.

"Standard Air"

As altitude increases, the average barometric pressure drops and air density decreases.

"Standard air" has historically been defined by ASHRAE as having a density of 0.075 lb/ft^3, which equates to air density at sea level (barometric pressure of 29.92 in. Hg). The 2009 *ASHRAE Handbook of Fundamentals* (page 18.13) states that this condition is represented by either saturated air at 60°F dry bulb or dry air at 69°F dry bulb.

Since the performance of heating, cooling, and air-moving equipment is commonly rated at "standard air" conditions, cataloged performance data cannot be used directly for higher altitude applications. For instance, at a barometric pressure of 24 in. Hg (approximately 6000 ft altitude), cataloged data may be off by as much as 20 to 40 percent.

While areas above 6000 ft are statistically limited, a number of states and cities have barometric pressures in the range of 29 to 27 in. Hg. In this range, cataloged ratings may differ from actual conditions by 3 to 20 percent.

Psychrometric Calculations

The equations used in psychrometric calculations remain the same for all altitudes. However, some of the factors used in these equations are affected by altitude.

The sensible heat gain (Q_S) equation is often displayed as follows:

$$Q_S = 1.085 \times \text{cfm} \times \Delta T$$

However, the 1.085 in this equation is not a constant. Rather, it is the product of the density (ρ) and specific heat (C_p) of the air at "standard air" conditions, and the conversion factor of 60 minutes per hour.

$$Q_S = (\rho \times C_p \times 60 \text{ min/hr}) \times \text{cfm} \times \Delta T$$

The specific heat for 69°F dry air at sea level is 0.241 Btu/lb°F. Therefore, at "standard air" conditions, these properties result in the value 1.085.

$$0.075 \text{ lb/ft}^3 \times 0.241 \text{ Btu/lb°F} \times 60 \text{ min/hr} = 1.085$$

The latent heat gain (Q_L) equation is often displayed as follows:

$$Q_L = 0.69 \times \text{cfm} \times \Delta W \text{ (gr/lb)}$$

However, the 0.69 in this equation is not a constant. Rather, it is the product of the density and latent heat of vaporization (Δh_{vap}) of the air at "standard air" conditions, and the conversion factors of 60 minutes per hour and 7000 grains/lb.

$$Q_L = (\rho \times \Delta h_{vap} \times 60 \text{ min/hr} / 7000 \text{ gr/lb}) \times \text{cfm} \times \Delta W$$

The latent heat of vaporization for 69°F dry air at sea level is 1076 Btu/lb. Therefore, at "standard air" conditions, these properties result in the value 0.69.

$$(0.075 \text{ lb/ft}^3 \times 1076 \text{ Btu/lb} \times 60 \text{ min/hr}) / 7000 \text{ gr/lb} = 0.69$$

The total heat gain (Q_T) equation is often displayed as follows:

$$Q_T = 4.5 \times \text{cfm} \times \Delta h$$

However, the 4.5 in this equation is not a constant. Rather, it is the product of the density of the air at "standard air" conditions and the conversion factor of 60 minutes per hour.

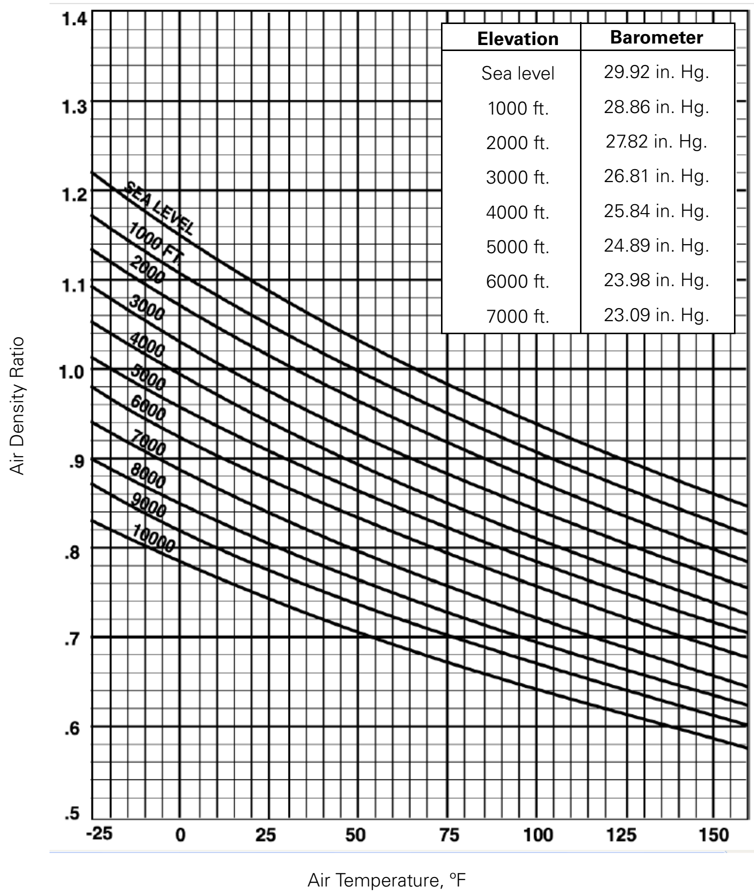
$$Q_T = (\rho \times 60 \text{ min/hr}) \times \text{cfm} \times \Delta h$$

For "standard air" density, the result is the value 4.5.

$$0.075 \text{ lb/ft}^3 \times 60 \text{ min/hr} = 4.5$$

Air at other conditions and other altitudes will cause these factors to change.

Figure 1. Air density ratios



Fans

Fans are considered to be constant-volume devices. That is, a given fan will deliver a specific volumetric flow rate (cfm) at a specific fan rotational speed (rpm). The mass of air that the fan moves at a given speed will vary based on the density of the air being moved. Air density also changes the static pressure that the fan will develop and the horsepower needed to drive it.

Fan and air handler manufacturers typically catalog fan performance data at "standard air" conditions. If the airflow requirement for a given application is stated at non-standard conditions, a density correction must be made prior to selecting a fan.

The procedure for selecting a fan at actual altitude (or temperatures) is outlined in the following steps:

1 Determine the actual air density and calculate the air density ratio, which is the density at actual conditions divided by density at standard conditions. Figure 1 provides a useful chart for determining the air density ratio based on altitude and air temperature.

$$\textbf{Air Density Ratio} = \frac{\textbf{Density}_{\textbf{actual}}}{\textbf{Density}_{\textbf{standard}}}$$

2 Divide the design static pressure at actual conditions by the air density ratio determined in Step 1.

$$\textbf{SP}_{\textbf{standard}} = \frac{\textbf{SP}_{\textbf{actual}}}{\textbf{Air Density Ratio}}$$

3 Use the actual design airflow (cfm) and the static pressure corrected for standard conditions (see Step 2) to select the fan from the performance tables/charts and to determine the speed (rpm) and horsepower requirement of the fan at standard conditions.

4 The fan speed (rpm) is the same at both actual and standard conditions.

$$\textbf{RPM}_{\textbf{actual}} = \textbf{RPM}_{\textbf{standard}}$$

5 Multiply the input power requirement by the air density ratio to determine the actual input power required.

$$\textbf{Power}_{\textbf{actual}} = \textbf{Air Density Ratio X Power}_{\textbf{standard}}$$

It is important to note that most pressure-loss charts for other system components (such as ducts, filters, coils, and dampers) are also based on standard air conditions.

Summary

Although the wide-scale use of computer software to select HVAC equipment has made the process of correcting for altitude simpler, a fundamental understanding is still important to prevent mistakes and troubleshoot problems.

By Trane Applications Engineering. You can find this and previous issues of the Engineers Newsletter at www.trane.com/engineersnewsletter. To comment, e-mail us at comfort@trane.com.

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THE BOILER HOUSE JOURNAL
NATURAL GAS DATA

Revised 4/3/06

We have compiled the following Natural Gas Data Tables for your use when selecting a gas fired appliance. We obtained the data from the Utility Companies' engineering and administrative offices. We must advise that the BTU values listed are average values and are not constant, as the Utility Company is unable to maintain exact values at the point of delivery. We suggest that you contact the utility company to confirm the BTU value of the gas at your location. It is also important to find out what the delivery pressure will be after the meter.

NATUAL GAS DATA TABLE

CITY	STATE	ALT.	BTU/CFH @ALT.	SPECIFIC GRAVITY	UTILITY CO.
Akron	CO	4662	835	.585	K N Energy
Alliance	NE	3959	898	.602	K N Energy
Alamosa	CO	7540	733	.60	Excel Energy
Antonito	CO	7888	764	.60	Excel Energy
Arvada	CO	5337	829	.67	Excel Energy
Aspen	CO	7908	770	.640	Kinder Morgan
Atwood	CO	3990	919	.65	Excel Energy
Ault	CO	7940	-----	-----	Excel Energy
Aurora	CO	5342	829	.67	Excel Energy
Avon	CO	7430	831	.65	Excel Energy
Avondale	CO	7550	854	.67	Excel Energy
Beaver Creek	CO	8300	806	.65	Excel Energy
Bellevue	CO	5120	877	.61	Excel Energy
Bergen Park	CO	7791	760	.67	Excel Energy
Berthoud	CO	5030	879	.61	Excel Energy
Big Horn	CO	8460	743	.67	Excel Energy
Black Hawk	CO	8460	754	.67	Excel Energy
Boone	CO	4500	854	.67	Excel Energy
Boulder	CO	5430	827	.67	Excel Energy
Bow Mar	CO	5500	825	.67	Excel Energy
Breckenridge	CO	9603	713	.67	Excel Energy
Bridge Port	NE	4000	898	.602	K N Energy
Brighton	CO	4982	881	.61	Excel Energy

CITY	STATE	ALT.	BTU/CFH @ALT.	SPECIFIC GRAVITY	UTILITY CO.
Broomfield	CO	5420	827	.67	Excel Energy
Brush	CO	4231	957	.67	Excel Energy
Buena Vista	CO	7953	800	.67	Comfort Gas Co.
Buffalo	WY	4645	935	.65	Mont Dakota Utility
Burlington	CO	4163	870	.65	Peoples Gas Co.
Burns	WY	5510	865	.61	Cheyenne Light & Power
Cameo	CO	4820	877	.65	Excel Energy
Campion	CO	5120	877	.61	Excel Energy
Canfield	CO	5015	880	.61	Excel Energy
Canon City	CO	5332	827	.65	Greeley Gas Co.
Capulin	CO	7810	766	.60	Excel Energy
Carpenter	WY	5436	867	.61	Cheyenne Light & Power
Casper	WY	5123	920	.65	Northern Utility
Castle Rock	CO	6202	770	.65	Peoples Gas Co.
Center	CO	7645	770	.60	Excel Energy
Central City	CO	8496	742	.67	Excel Energy
Chadron	NE	3400	920	.602	K N Energy
Chappel	NE	3800	905	.602	K N Energy
Cherry Hills Village	CO	5381	828	.67	Excel Energy
Cheyenne	WY	6100	847	.61	Cheyenne Light & Power
Cheyenne Wells	CO	4296	976	.65	Peoples Gas Co.
Clifton	CO	4710	881	.65	Excel Energy
Climax	CO	11,320	671	.67	Excel Energy
Coal Creek	CO	5600	755	.67	Excel Energy
Cody Park	CO	7400	771	.67	Excel Energy
Collbran	CO	5987	935	.657	Kinder Morgan
Colo. Springs	CO	6012	807	.639	City of Colo. Springs
Columbine Valley	CO	5280	831	.67	Excel Energy
Commerce City	CO	5150	835	.67	Excel Energy
Conejos	CO	7800	766	.60	Excel Energy
Conifer	CO	8270	748	.67	Excel Energy
Copper Mountain	CO	9680	711	.67	Excel Energy
Cortez	CO	6198	861	.611	Greeley Gas Co.
Craig	CO	6185	848	.653	Excel Energy
Crawford	NE	3600	913	.602	K N Energy
Crested Butte	CO	8900	729	.609	Excel Energy
Dacono	CO	5017	960	.65	Assoc. Nat. Gas
De Beque	CO	4935	934	.62	Excel Energy
Deer Trail	CO	5183	820	.65	East Colo. Utility
Del Norte	CO	7874	764	.60	Excel Energy
Delta	CO	4961	820	.59-.63	Kinder Morgan
Denver	CO	5280	831	.67	Excel Energy
Denver Int'l Airport	CO	5431	867	.61	Excel Energy
Denver N.E.	CO	5280	868	.61	Excel Energy

CITY	STATE	ALT.	BTU/CFH @ALT.	SPECIFIC GRAVITY	UTILITY CO.
Dillon	CO	9156	725	.67	Excel Energy
Douglas	WY	4815	873	.601	K N Energy
Dove Creek	CO	6843	840	.611	Greeley Gas Co.
Downieville	CO	8000	755	.67	Excel Energy
Dumont	CO	7950	756	.67	Excel Energy
Dupont	CO	5110	836	.67	Excel Energy
Durango	CO	6512	906	.695	Greeley Gas Co.
Eads	CO	4213	903	.625	Greeley Gas Co.
Eagle	CO	6600	830	.65	Kinder Morgan
Eastlake	CO	5270	831	.67	Excel Energy
Eaton	CO	4839	929	.656	Greeley Gas Co.
Eckley	CO	3894	895	.657	K N Energy
Edgewater	CO	5355	829	.67	Excel Energy
Eldora	CO	8700	736	.67	Excel Energy
Eldorado Springs	CO	5750	817	.67	Excel Energy
Empire	CO	8601	739	.67	Excel Energy
Englewood	CO	5306	830	.67	Excel Energy
Erie	CO	5038	879	.61	Excel Energy
Estes Park	CO	7522	805	.61	Excel Energy
Evergreen	CO	7040	781	.67	Excel Energy
Federal Heights	CO	5535	824	.67	Excel Energy
Flagler	CO	4931	840	.65	Peoples Gas Co.
Fleming	CO	4240	890	.657	Peoples Gas Co.
Fort Carson	CO	6012	807	.639	City of Colo. Springs
Florence	CO	5187	832	.65	Greeley Gas Co.
Fort Collins	CO	4984	881	.61	Excel Energy
Fort Lupton	CO	4914	883	.61	Excel Energy
Fort Morgan	CO	4321	1000	.63	Ft. Morgan Gas Co.
Fraser	CO	8550	740	.67	Excel Energy
Frederick	CO	4982	960	.65	Kinder Morgan
Frisco	CO	9097	726	.67	Excel Energy
Front Range Airport	CO	5450	916	.67	Excel Energy
Fruita	CO	4498	887	.65	Excel Energy
Fruitvale	CO	4660	882	.65	Excel Energy
Georgetown	CO	8519	741	.67	Excel Energy
Gering	NE	4000	898	.602	K N Energy
Gillette	WY	4544	980	.65	Mont. Dakota Utility
Glendale	CO	5350	829	.67	Excel Energy
Glenrock	WY	5009	866	.601	K N Energy
Glenwood Springs	CO	5746	804	.650	Kinder Morgan
Golden	CO	5675	820	.67	Excel Energy
Gordon	NE	3500	839	.585	K N Energy
Granby	CO	7935	757	.67	Excel Energy

CITY	STATE	ALT.	BTU/CFH @ALT.	SPECIFIC GRAVITY	UTILITY
Grand Junction	CO	4586	884	.65	Excel Energy
Grand Lake	CO	8437	743	.67	Excel Energy
Greybull	WY	3788	920	.65	Wyoming Gas Co.
Greeley	CO	4663	906	.656	Greeley Gas Co.
Green Valley Ranch	CO	5410	868	.61	Excel Energy
Greenwood Village	CO	5422	827	.67	Excel Energy
Guadalupe	CO	7900	763	.60	Excel Energy
Gun Barrel Green	CO	5192	874	.61	Excel Energy
Gunnison	CO	7703	751	.609	Excel Energy
Hanna	WY	6777	935	.65	Northern Gas Co.
Haxtun	CO	4028	858	.585	K N Energy
Hazeltine	CO	5080	837	.61	Excel Energy
Henderson	CO	5020	839	.67	Excel Energy
Hideaway Park	CO	8800	734	.67	Excel Energy
Holyoke	CO	3746	866	.585	K N Energy
Holly	CO	3397	1010	.736	Greeley Gas Co.
Homelake	CO	7620	771	.60	Excel Energy
Hot Sulphur Spgs.	CO	7670	764	.67	Excel Energy
Hygiene	CO	5090	878	.61	Excel Energy
Hudson	CO	5024	920	.664	Kinder Morgan
Hudson	WY	5094	820	.65	Northern Gas Co.
Hugo	CO	5046	780	.65	Peoples Gas Co.
Idaho Springs	CO	7540	767	.67	Excel Energy
Idledale	CO	6460	797	.67	Excel Energy
Iliff	CO	3833	895	.657	K N Energy
Indian Hills	CO	6840	786	.67	Excel Energy
Johnstown	CO	4820	886	.61	Excel Energy
Julesburg	CO	3477	916	.602	K N Energy
Keystone	CO	9200	724	.67	Excel Energy
Kimball	NE	4800	877	.608	K N Energy
Kittredge	CO	6810	787	.67	Excel Energy
Kremmling	CO	7364	772	.67	Excel Energy
La Jara	CO	7602	771	.60	Excel Energy
La Junta	CO	4188	850	.69	Citizens Utility Co.
Lafayette	CO	5237	832	.67	Excel Energy
Lakewood	CO	5440	826	.67	Excel Energy
Lamar	CO	3622	1003	.736	Greeley Gas Co.
Lander	WY	5360	950	.60	Northern Gas Co.
La Porte	CO	5060	878	.61	Excel Energy
Laramie	WY	7165	820	.65	Northern Gas Co.
Las Animas	CO	3901	735	.62	Citizens Utility Co.

CITY	STATE	ALT.	BTU/CFH @ ALT.	SPECIFIC GRAVITY	UTILITY CO.
Lawson	CO	8120	752	.67	Excel Energy
Leadville	CO	10,152	700	.67	Excel Energy
Leyden	CO	5650	820	.67	Excel Energy
Limon	CO	5366	840	.67	Peoples Gas Co.
Littleton	CO	5362	829	.67	Excel Energy
Lochbuie	CO	4980	881	.61	Excel Energy
Log Lane Village	CO	4330	953	.67	Excel Energy
Longmont	CO	4974	881	.61	Excel Energy
Lookout Mountain	CO	7374	772	.67	Excel Energy
Louisville	CO	5350	829	.67	Excel Energy
Louviers	CO	5680	819	.67	Excel Energy
Loveland	CO	4982	881	.67	Excel Energy
Lusk	WY	5015	863	.602	K N Energy
Lyons	CO	5473	869	.61	Excel Energy
Manassa	CO	7683	769	.60	Excel Energy
Manitou Springs	CO	6412	807	.639	City of Colo. Spgs.
Mead	CO	5140	876	.61	Excel Energy
Meeker	CO	6242	850	.653	Greeley Gas Co.
Merino	CO	4035	994	.67	Excel Energy
Milliken	CO	4760	888	.61	Excel Energy
Minturn	CO	7817	820	.65	Excel Energy
Monte Vista	CO	7663	770	.60	Excel Energy
Montezuma	CO	10,280	696	.67	Excel Energy
Montrose	CO	5794	770	.683	Kinder Morgan
Monument	CO	6960	780	.65	Peoples Gas Co.
Morgan Heights	CO	4330	953	.67	Excel Energy
Morrison	CO	5800	816	.67	Excel Energy
Mountain View	CO	5385	828	.67	Excel Energy
Mt. Vernon	CO	7413	771	.67	Excel Energy
New Castle	CO	5550	905	.62	Excel Energy
New Castle	WY	4334	880	.62	Mont. Dakota Utility
Nederland	CO	8236	749	.67	Excel Energy
Niwot	CO	5090	828	.61	Excel Energy
Northglenn	CO	5460	826	.67	Excel Energy
Orchard Mesa	CO	4650	882	.65	Excel Energy
Otis	CO	4335	890	.657	K N Energy
Ovid	CO	3521	820	.60	K N Energy
Pagosa Springs	CO	7079	750	.65	Citizens Utility Co.
Palisade	CO	4727	880	.65	Excel Energy
Paoli	CO	3898	895	.657	K N Energy
Parachute	CO	5095	928	.62	Excel Energy
Parker	CO	5870	814	.67	Excel Energy

CITY	STATE	ALT.	BTU/CFH @ALT.	SPECIFIC GRAVITY	UTILITY CO.
Parshall	CO	7560	767	.67	Excel Energy
Pavillion	WY	5690	860	.65	Northern Gas Co.
Pine	CO	6754	789	.67	Excel Energy
Pine Bluffs	WY	5050	879	.61	Cheyenne Light & Power
Pinedale	WY	7175	1550	LP/air	Western Utility
Platteville	CO	4820	901	.656	Greeley Gas Co.
Powell	WY	4365	940	.65	Wyoming Gas Co.
Pueblo	CO	4639	849	.67	Excel Energy
Rangley	CO	5250	960	.65	City of Rangley
Rawlins	WY	6755	835	.65	Northern Gas Co.
Red Cliff	CO	8150	735	.67	Excel Energy
Richfield	CO	7590	772	.60	Excel Energy
Rifle	CO	5345	911	.62	Excel Energy
Riverton	WY	4946	950	.60	Northern Gas Co.
Rock Springs	WY	6271	870	.60	Mt. Fuel Nt. Gas
Rocky Ford	CO	4178	740	.67	Citizens Utility Co.
Romeo	CO	7750	767	.60	Excel Energy
Russell Gulch	CO	9140	725	.67	Excel Energy
Saguache	CO	7697	769	.60	Excel Energy
Salida	CO	7036	777	.609	Greeley Gas Co.
Sanford	CO	7560	772	.60	Excel Energy
Saratoga	WY	6786	935	.65	Northern Gas Co.
Sargent	CO	7920	763	.60	Excel Energy
Scottsbluff	NE	4000	898	.602	K N Energy
Sedalia	CO	5860	814	.67	Excel Energy
Severance	CO	4890	884	.61	Excel Energy
Sheridan	CO	5307	830	.67	Excel Energy
Sheridan	WY	3745	860	.65	Mont. Dakota Utility
Shoshoni	WY	4820	940	.65	Northern Gas Co.
Sidney	NE	4000	898	.602	K N Energy
Silt	CO	5432	908	.62	Excel Energy
Silver Plume	CO	9118	726	.67	Excel Energy
Silverthorne	CO	8790	734	.67	Excel Energy
Sinclair	WY	6592	840	.65	Northern Gas Co.
Snowmass Village	CO	8575	751	.640	Kinder Morgan
Springfield	CO	4365	943	.627	Greeley Gas Co.
Steamboat Spgs.	CO	6687	837	.642	Greeley Gas Co.
Sterling	CO	3935	921	.65	Excel Energy
Stratton	CO	4414	880	.65	Peoples Gas Co.
Strasburg	CO	5380	840	.65	East Colo. Utility
Superior	CO	5512	824	.67	Excel Energy
Tabernash	CO	8320	746	.67	Excel Energy
Telluride	CO	8745	696	.595	Kinder Morgan

CITY	STATE	ALT.	BTU/CFH @ALT.	SPECIFIC GRAVITY	UTILITY
Thermopolis	WY	4326	885	.65	Wyoming Gas Co.
Thornton	CO	5400	831	.67	Excel Energy
Timnath	CO	4877	884	.61	Excel Energy
Torrington	WY	4104	895	.602	K N Energy
Trinidad	CO	5746	980	.65	K N Energy
Vail	CO	8150	810	.65	Excel Energy
Vineland	CO	4640	850	.67	Excel Energy
Walden	CO	8099	720	.67	Kinder Morgan
Walsenburg	CO	6220	747	.65	City of Walsenburg
Wah Keeney Park	CO	7600	771	.67	Excel Energy
Weldona	CO	4340	953	.67	Excel Energy
Wellington	CO	5201	874	.61	Kinder Morgan
West Vail	CO	8000	814	.65	Excel Energy
Westminster	CO	5445	831	.67	Excel Energy
Wheat Ridge	CO	5445	826	.67	Excel Energy
Wheatland	WY	4733	872	.858	K N Energy
Widefield	CO	5730	820	.65	Peoples Gas Co.
Wiggins	CO	4540	895	.61	Excel Energy
Windsor	CO	4800	867	.61	Excel Energy
Winter Park	CO	9100	726	.67	Excel Energy
Woodland Park	CO	8465	705	.65	Peoples Gas Co.
Worland	WY	4061	940	.65	Wyoming Gas. Co.
Wray	CO	3516	872	.595	K N Energy
Yuma	CO	4125	890	.657	K N Energy

PLEASE NOTE: We have made every effort possible to ensure the accuracy of the data included, however, Engineered Products Company and *The Boiler House Journal* cannot guarantee total accuracy.